Towards a Global Carbon Observing System: Progresses and Challenges

Geneva, 1-2 October 2013

Precision and accuracy of *in situ* tower-based carbon cycle concentration networks required for detection of the effects of extreme climate events on regional carbon cycling

Ankur R Desai

University of Wisconsin-Madison

desai@aos.wisc.edu

Precision and accuracy of *in situ* tower based carbon cycle concentration networks required for detection of the effects of extreme climate events on regional carbon cycling

Ankur R Desai, Arlyn Andrews, Britt Stephens, Bjorn Brooks, Dong Hua, and many other collaborators…

WISCONSIN
UNIVERSITY OF WISCONSIN–MADISON

NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
U.S. DEPARTMENT OF COMMERCE

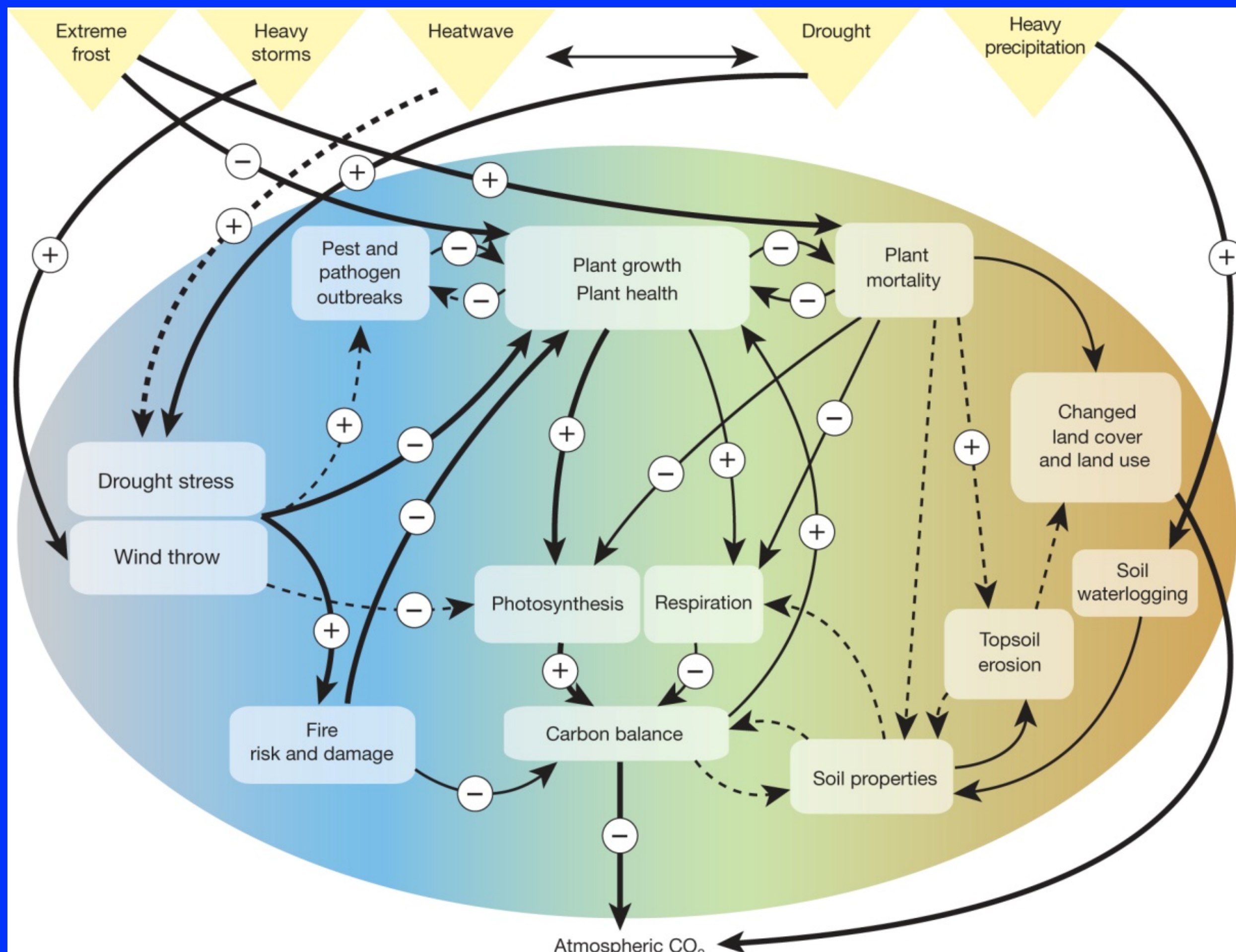
NCAR
NATIONAL CENTER FOR ATMOSPHERIC RESEARCH

ST. FRANCIS XAVIER UNIVERSITY

Questions

- What is required of continental atmospheric greenhouse gas observations for observing regional carbon fluxes?
  - More specifically, observing response of these fluxes to extreme climate events or other significant changes?
  - Further, to what extent can we disentangle "well-mixed" measurements to detect regional hotspots (or cold spots) of terrestrial sinks and sources?

Processes and feedbacks triggered by extreme climate events.



M Reichstein *et al.* *Nature* **500**, 287-295 (2013) doi:10.1038/nature12350

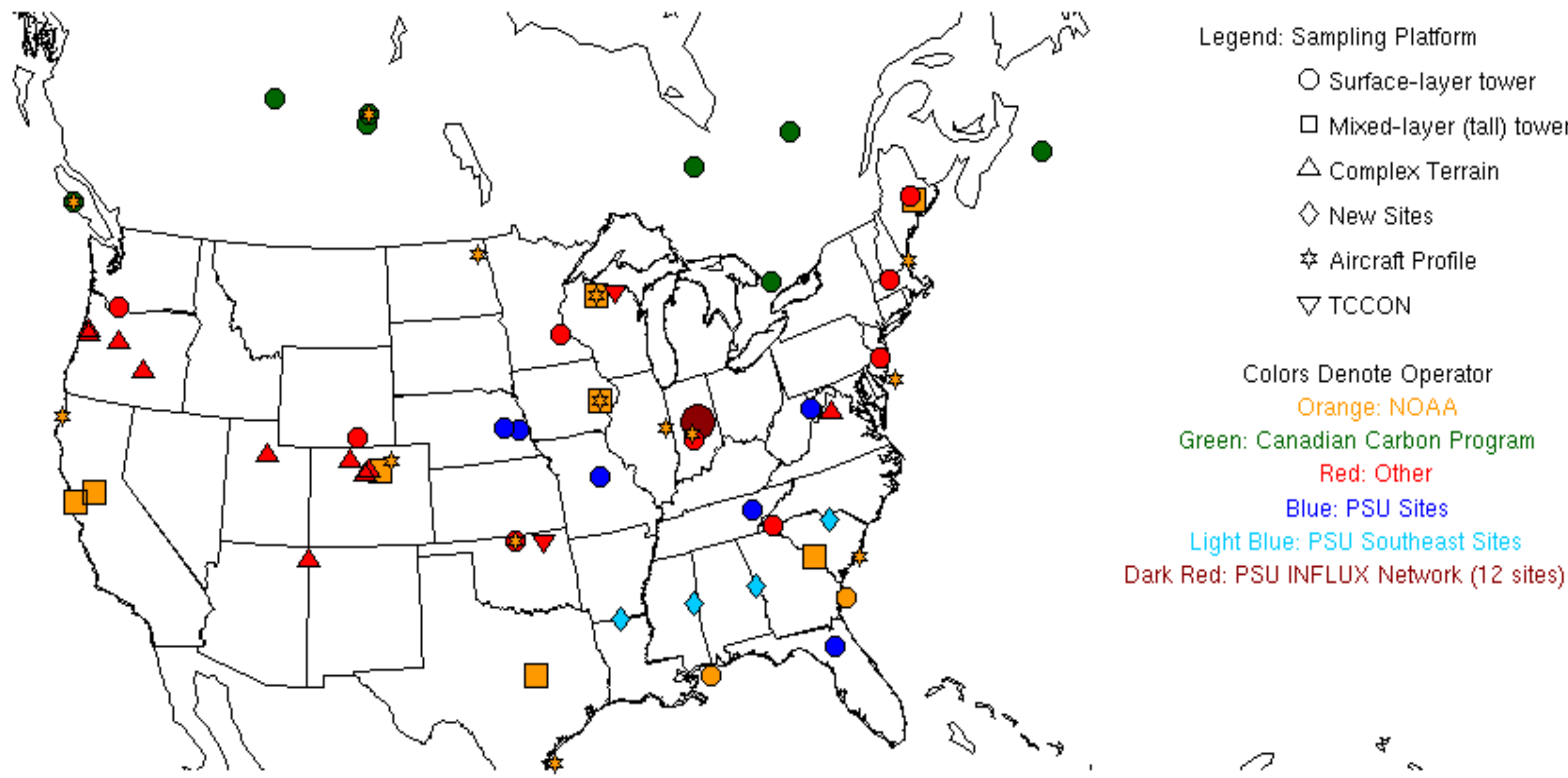
Outline

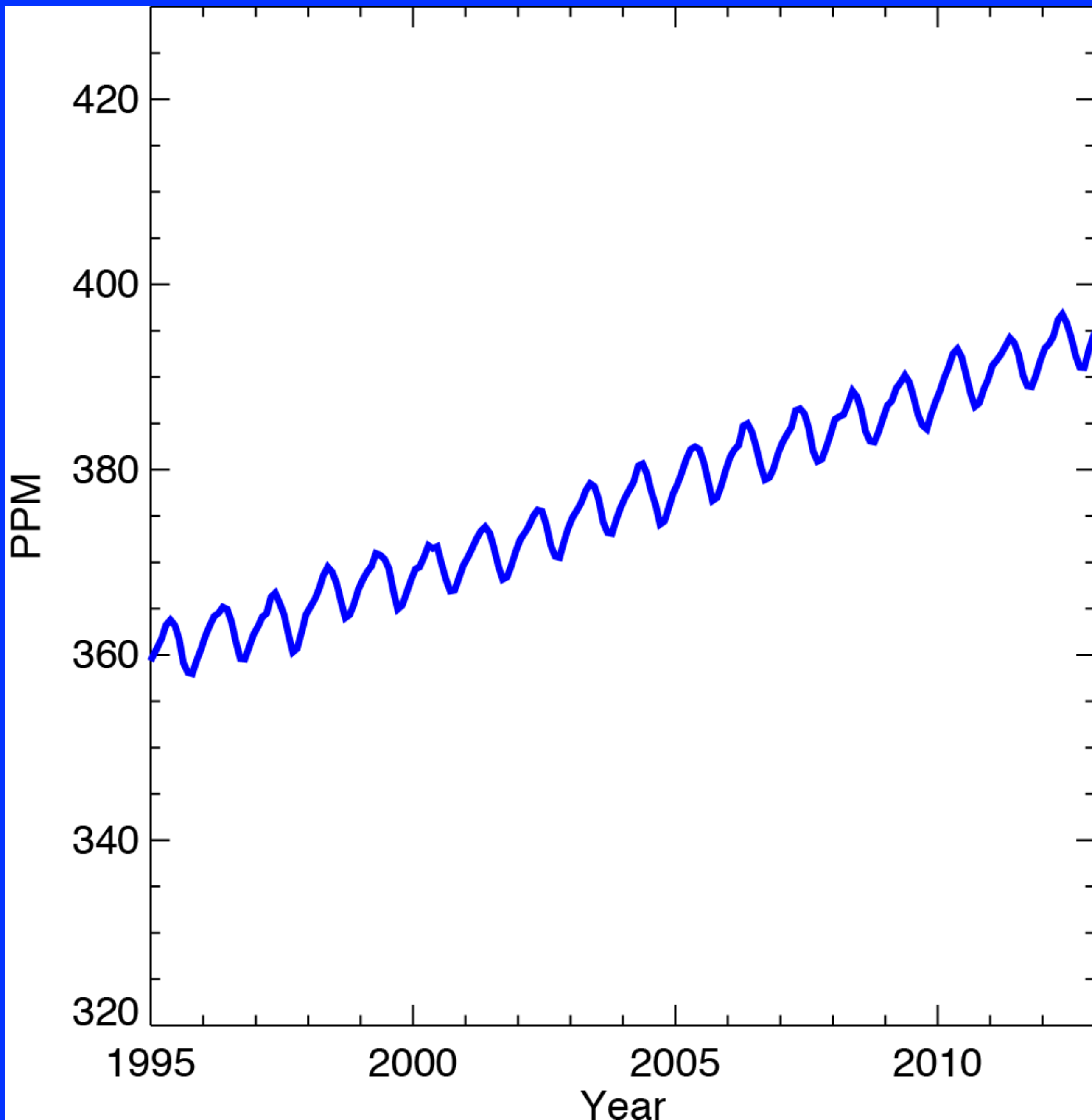
- Building a tower network with sufficient reliability and accuracy
- Example 1. Simulations of drought impacts on atmospheric CO_2
- Example 2. Detection of large-scale insect disturbance on forest productivity and decomposition
- Example 3. Searching for hot-spots of inland water carbon emissions
- Summary and recommendations

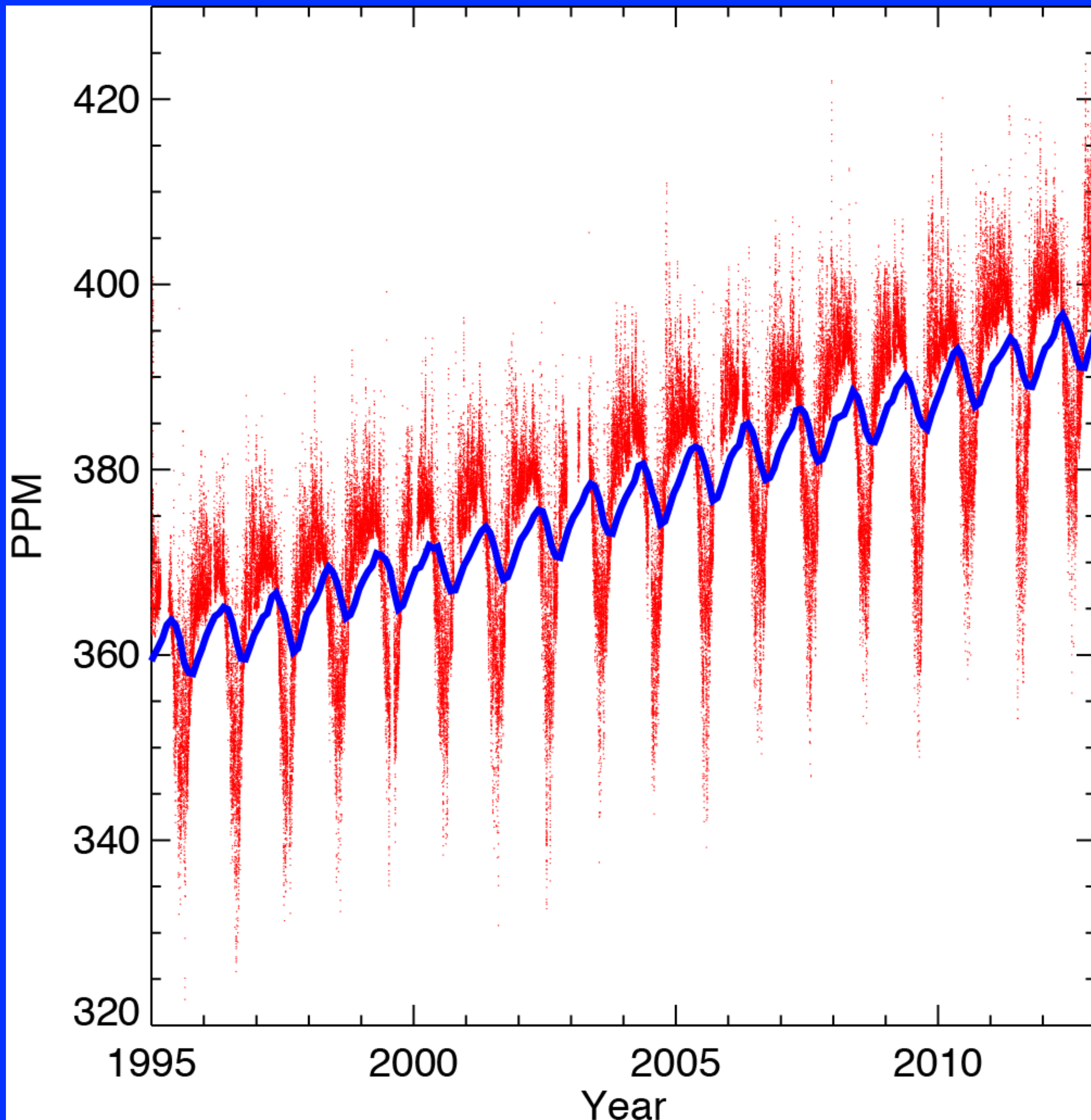
Building a tower network

From: Andrews, A.E. et al., 2013. CO2, CO and CH4 measurements from the NOAA Earth System Research Laboratory's Tall Tower Greenhouse Gas Observing Network: instrumentation, uncertainty analysis and recommendations for future high-accuracy greenhouse gas monitoring efforts. *Atmos. Meas. Tech. Discuss.*, 6, 1461-1553, doi: 10.5194/amtd-6-1461-2013.

Well-calibrated North American CO_2 sites

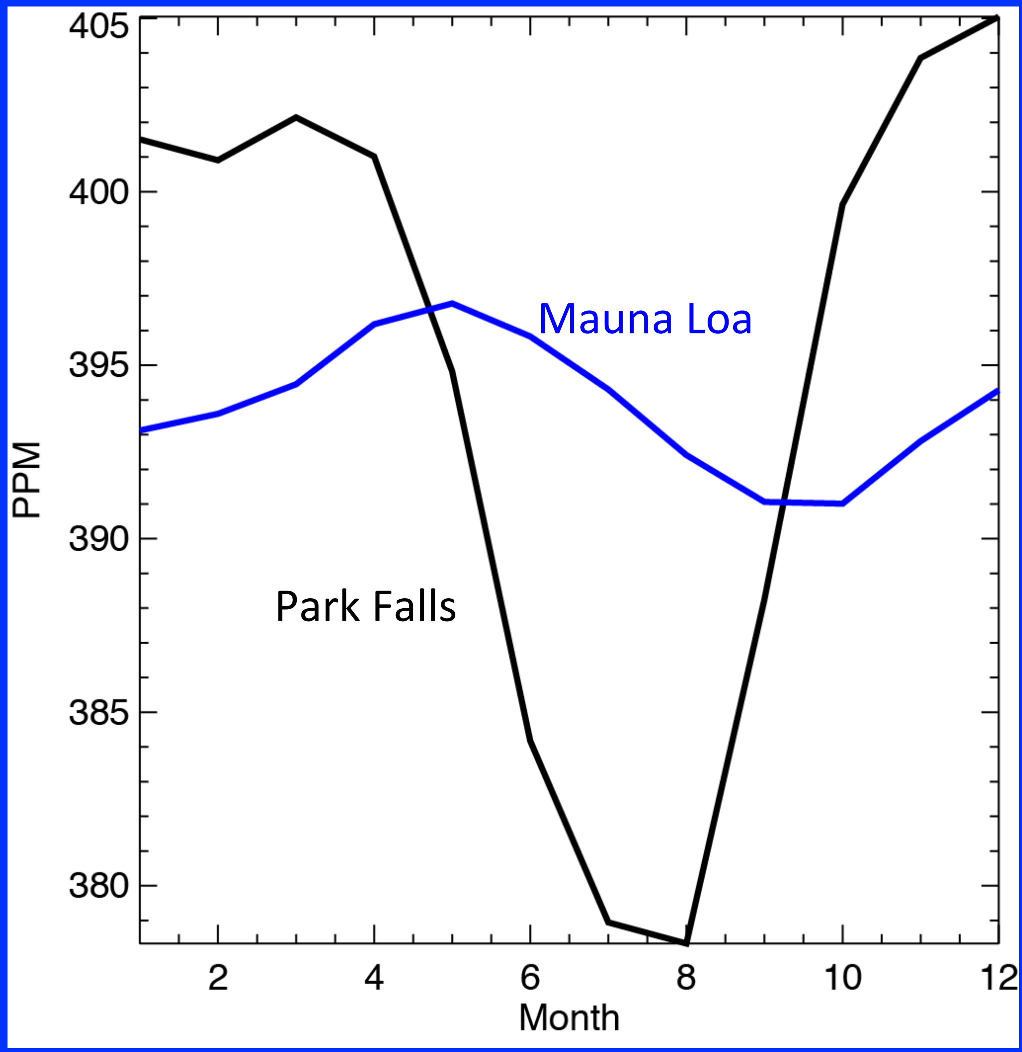



420
400
380
360
340
320
PPM
1995
2000
2005
2010
Year

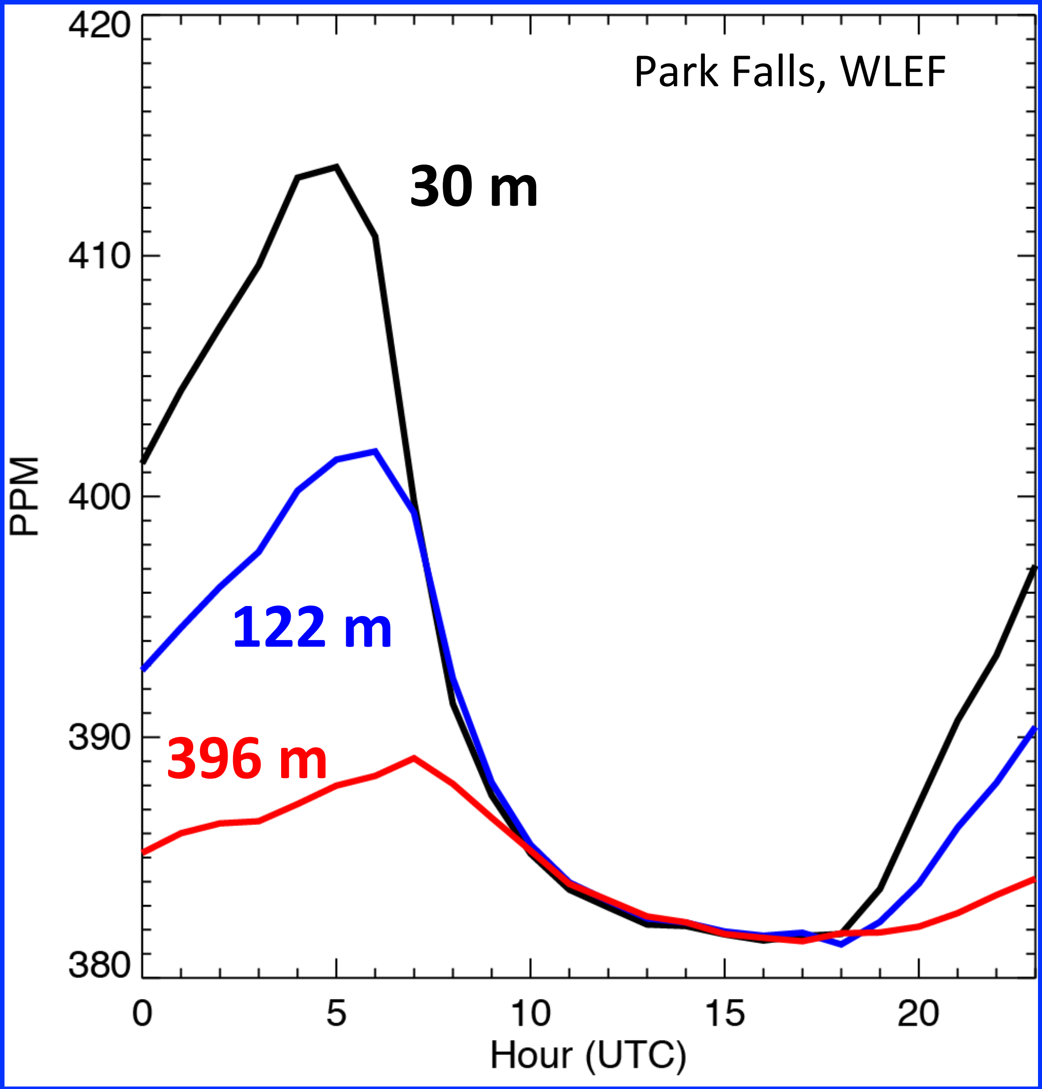


420
400
380
360
340
320
PPM
1995
2000
2005
2010
Year

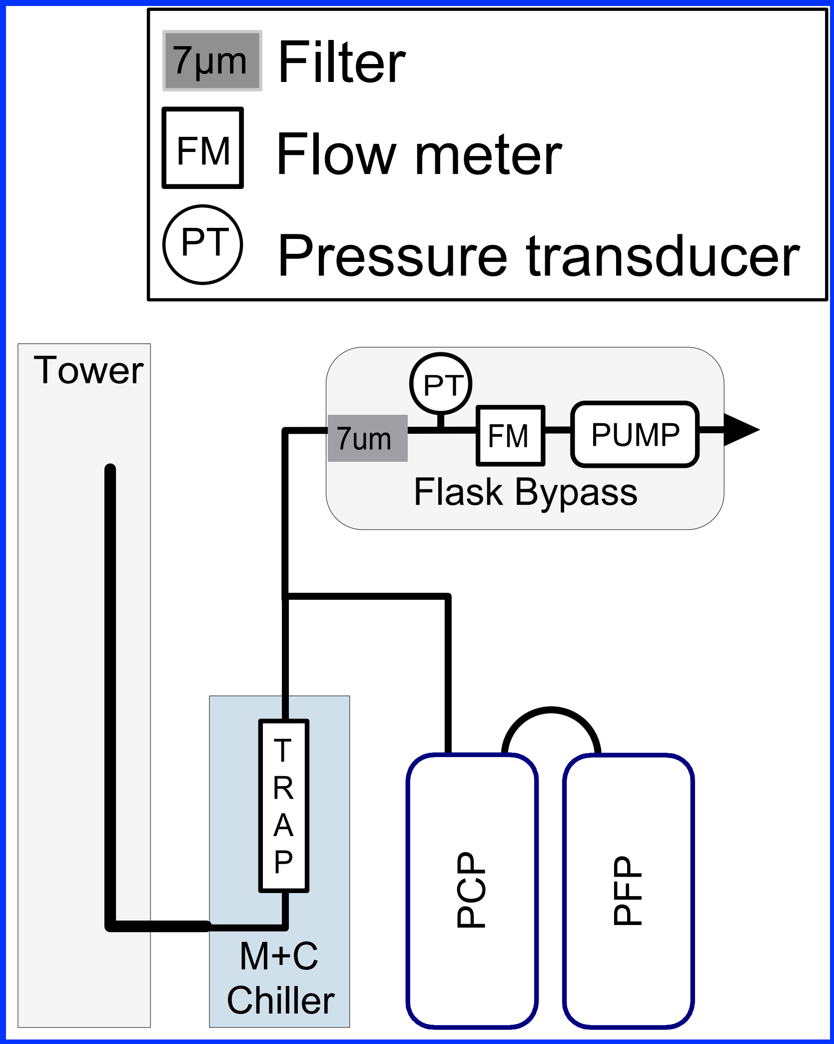
Seasonality enhanced by dynamic boundary layer and large seasonal flux signal



Diurnal amplitudes are a function of height and time of day

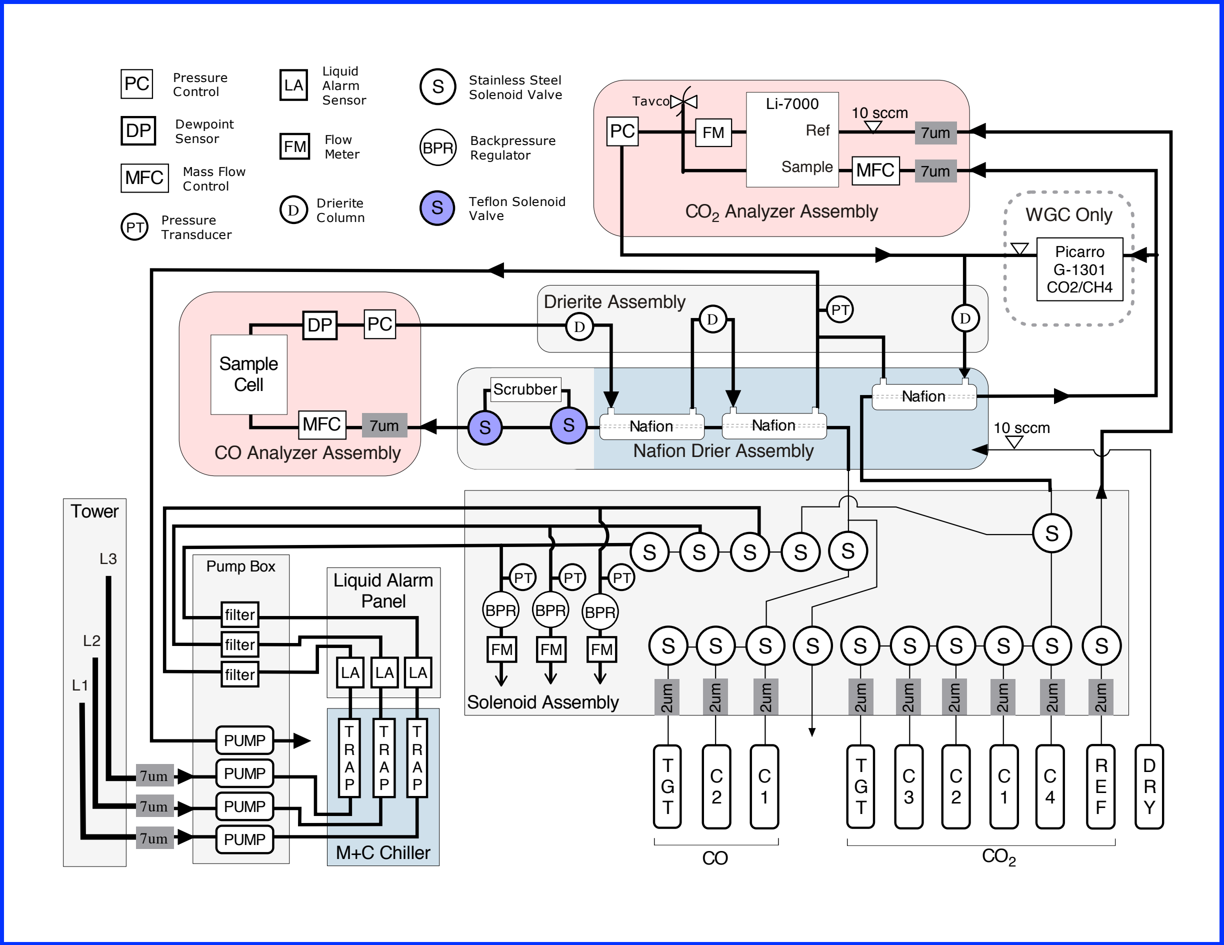


Flask sampling is relatively straightforward

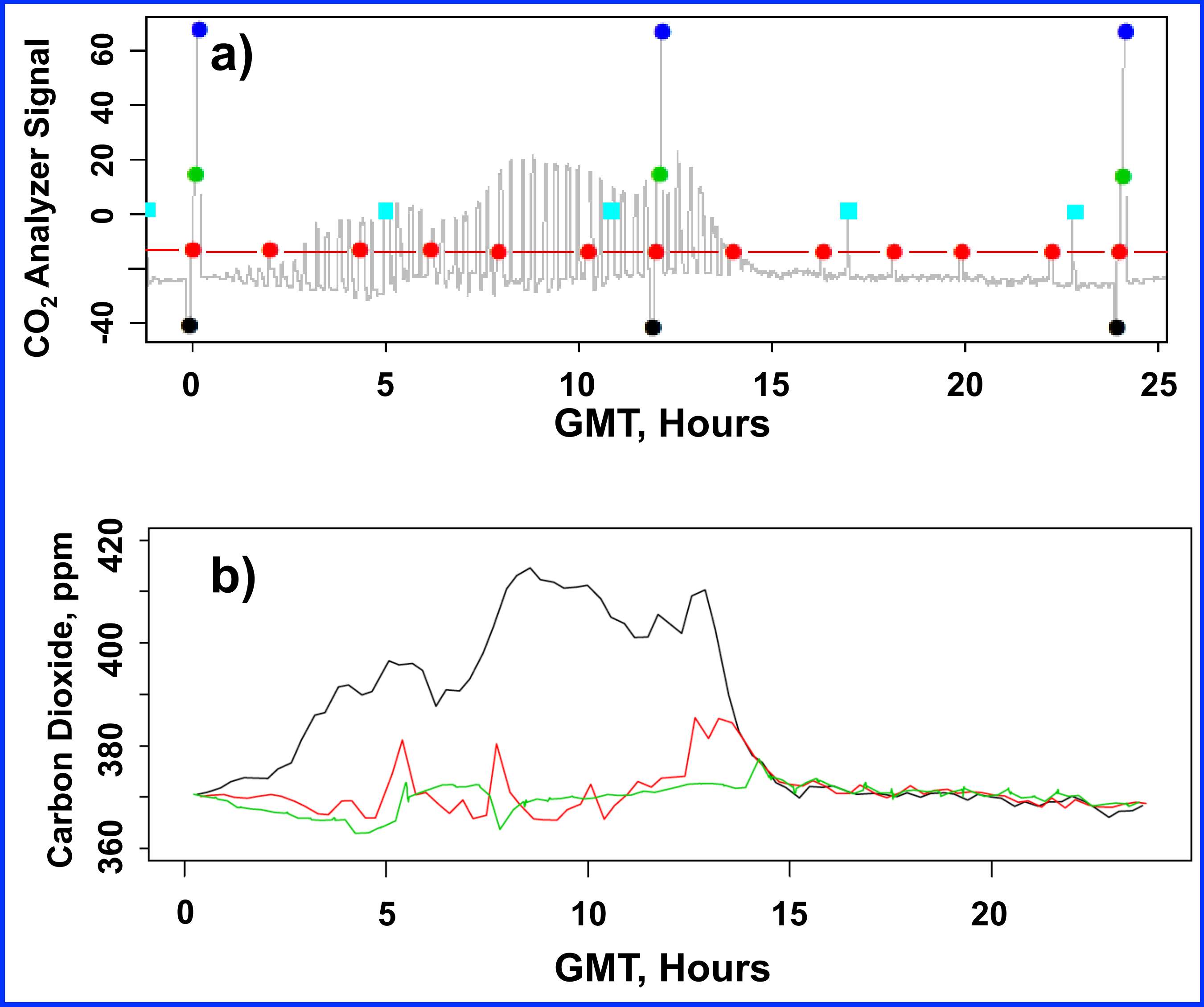


Continuous is a wee bit more complicated

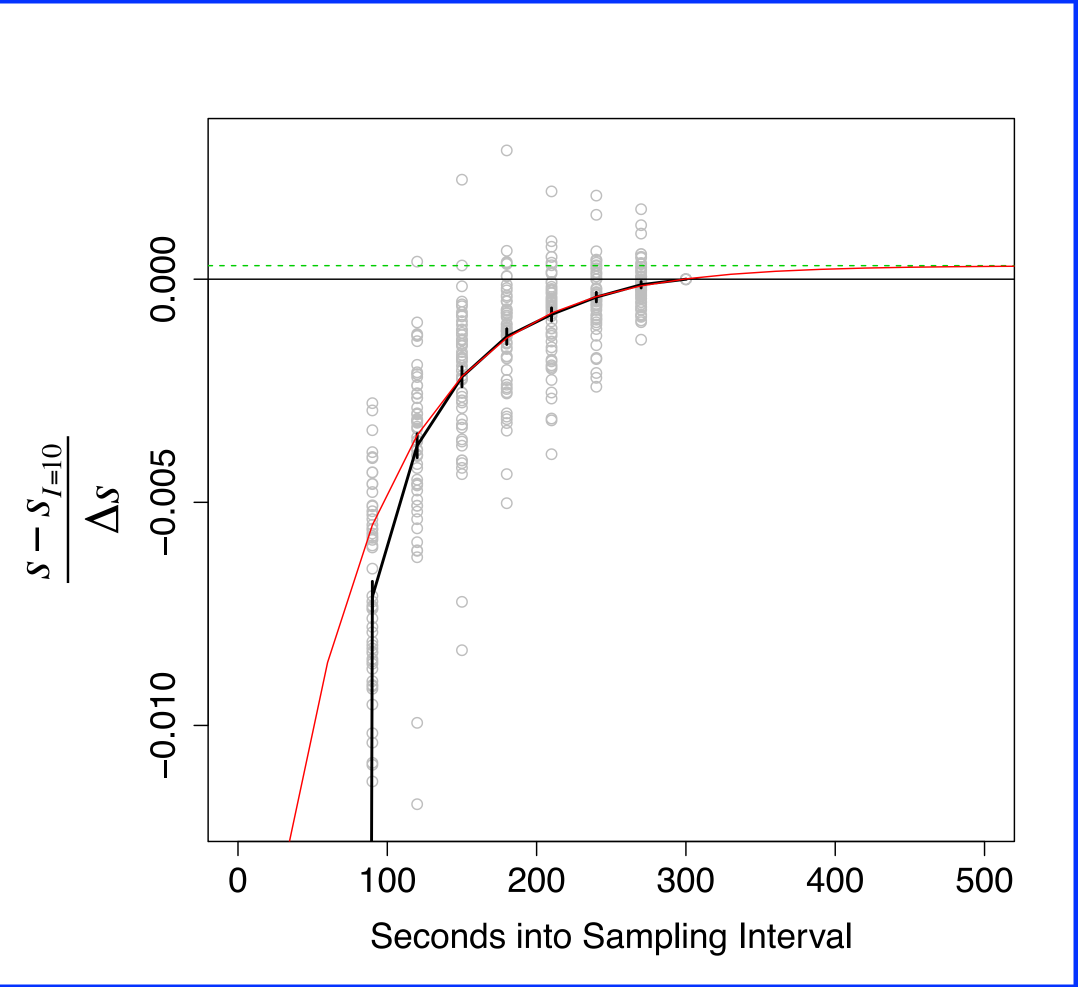
- NOAA ESRL system based on LI-7000



Target tank calibration sequence



Dwell time matters



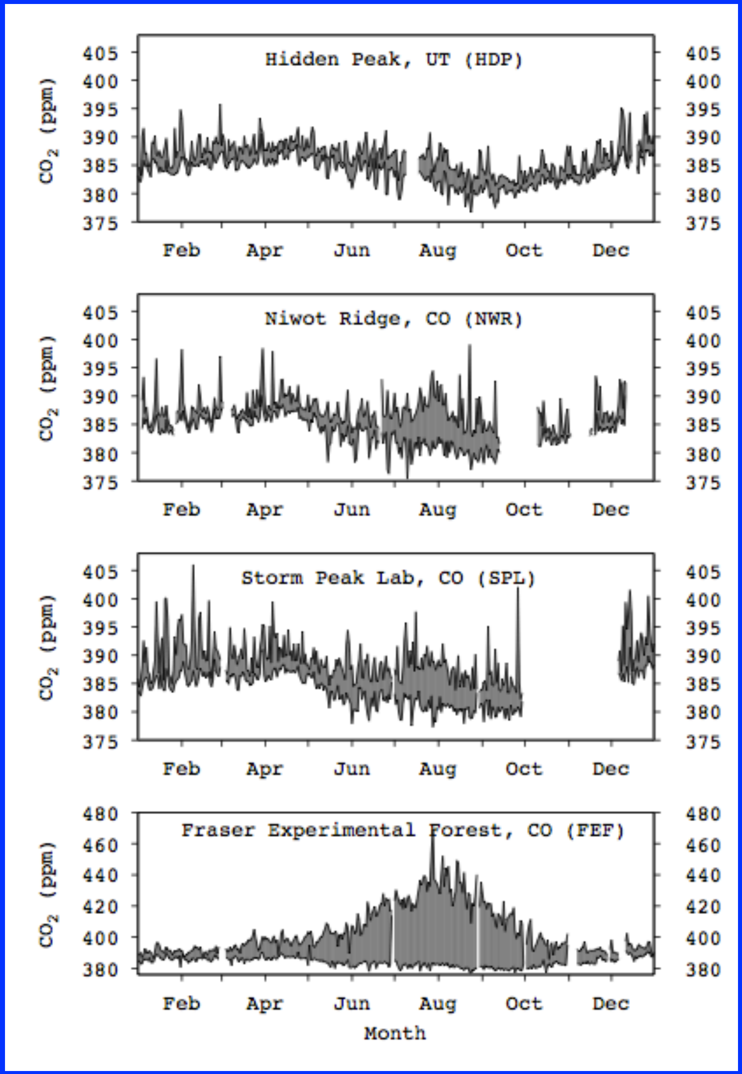
Targets

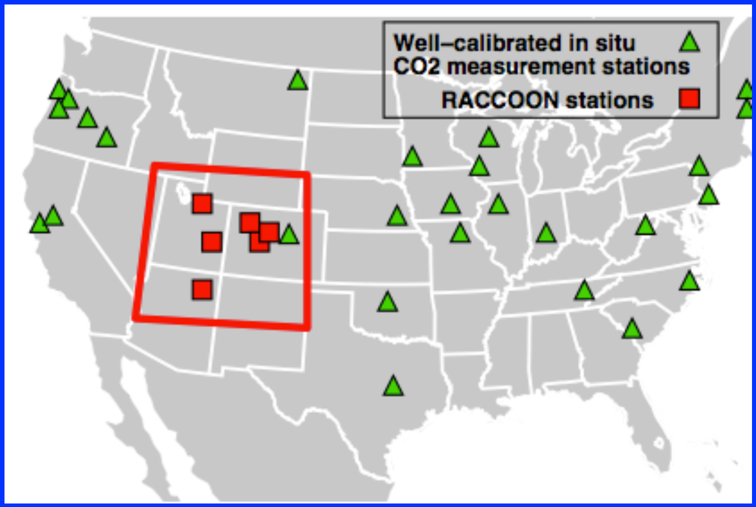
- Can generally sample 5-minute concentrations to within 0.1 ppm using NOAA ESRL tall tower sampling system
- Primary sources of uncertainty:
  - WMO calibration scale (0.069 ppm)
  - short-term precision (***u_p***) (0.004 ppm) + atmospheric variability within sample interval (0.2-1 ppm)
  - Baseline drift (***u_b***) (0.006 ppm)
  - Calibration curve fitting (***u_f***) (0.038 ppm) + extrapolation beyond fit (***u_{ex}***) *(~0 ppm)*
  - Sample gas equillibriation (***u_{eq}***) (~0 ppm)
  - Water vapor dilution (***u_{wv}***) (0.001 ppm)
  - Contamination/leaks (??)
  - Net uncertainty ~0.007 ppm
  - Total error – 0.109 ppm
  - Target tank bias – 0.052 ppm
  - 30-s std dev – 0.056 ppm

$$\sigma_u^2 = u_p^2 + u_b^2 + u_{ex}^2 + u_{eq}^2 + u_{wv}^2$$

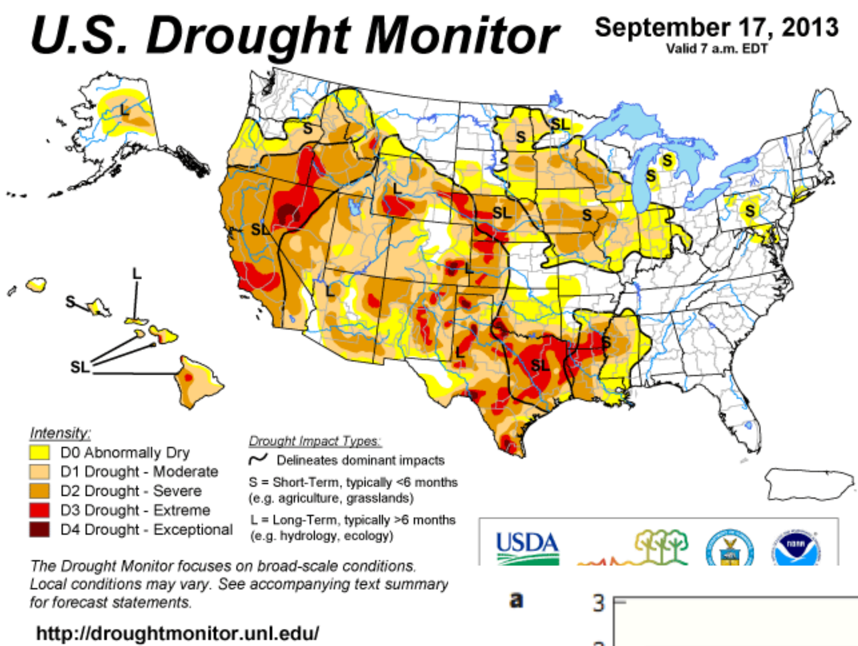
$$u_M = z_{(\alpha/2, f)} \sqrt{u_f^2 + \sigma_u^2}$$

Example 1. Drought

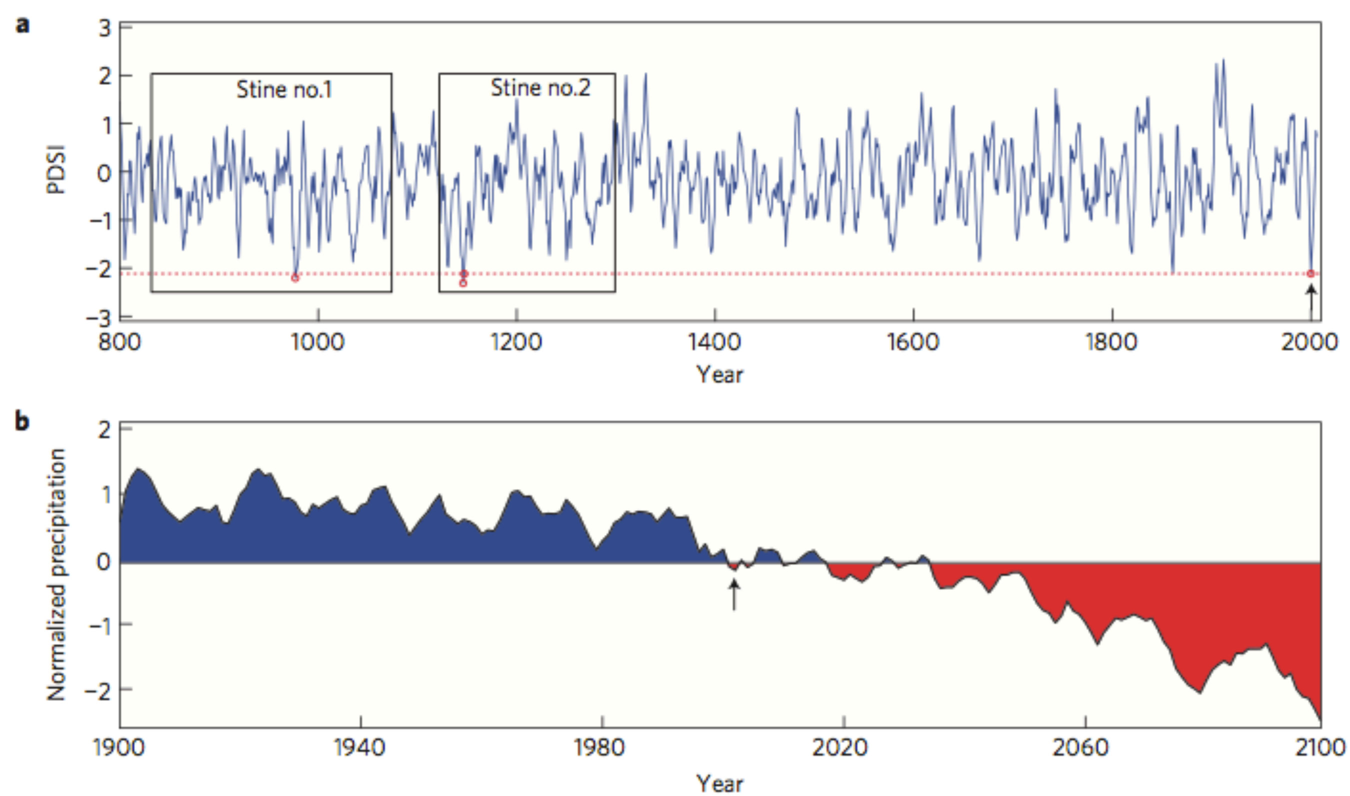




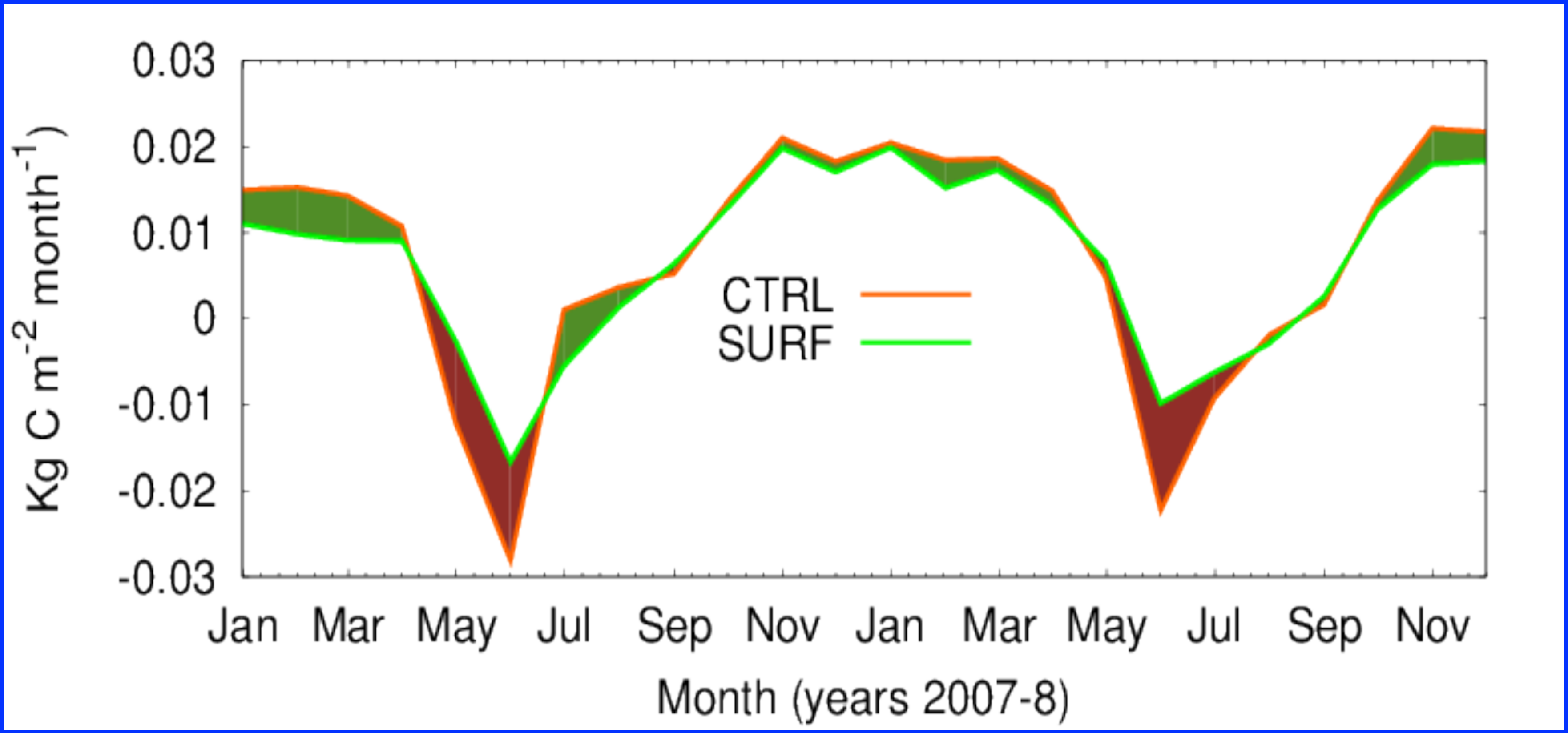
Brooks, Hua, Desai, et al., in prep



Schwalm et al., 2012. *Nature Geosci*

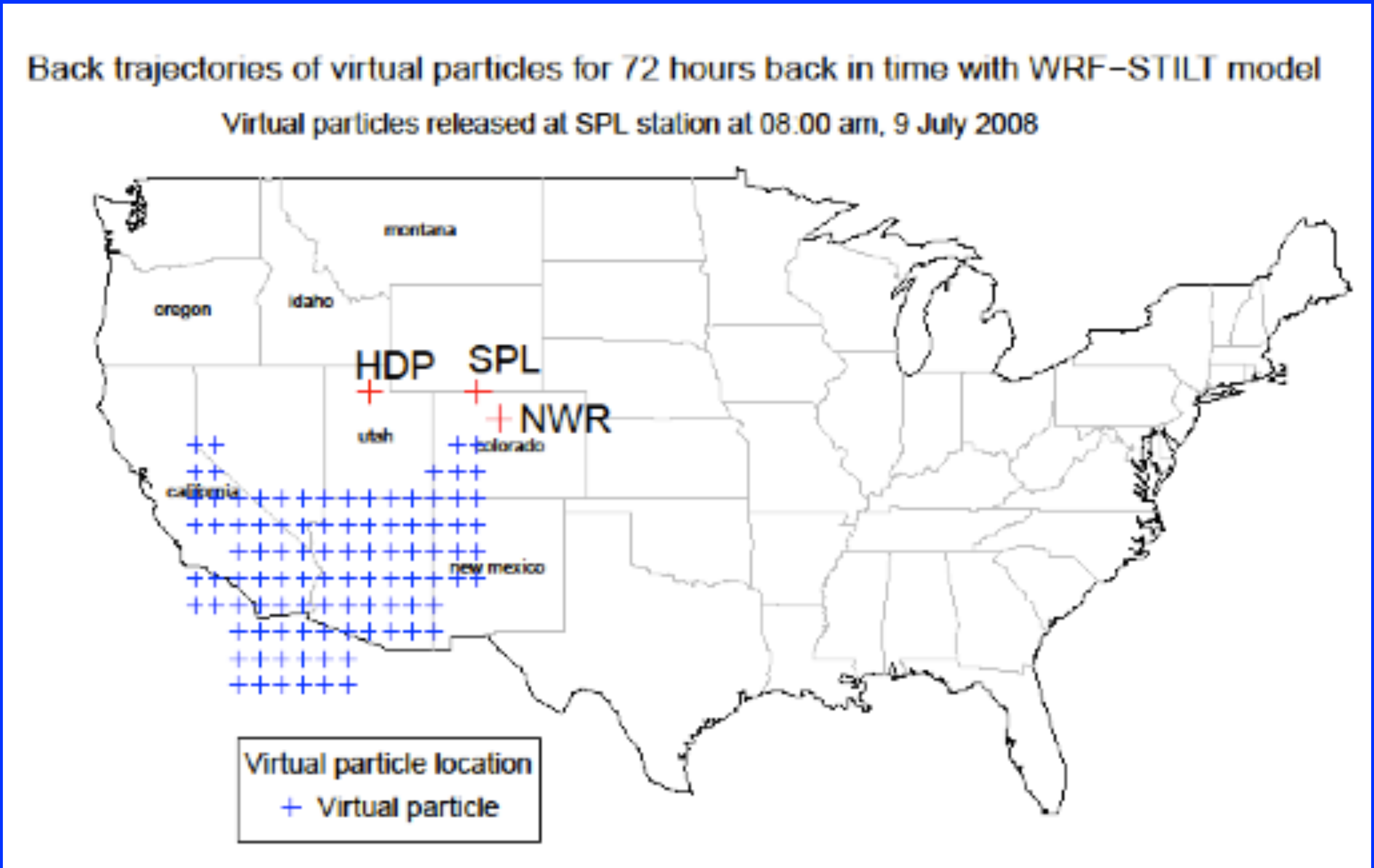


Inverse models (CarbonTracker) are sensitive to mountaintop CO_2

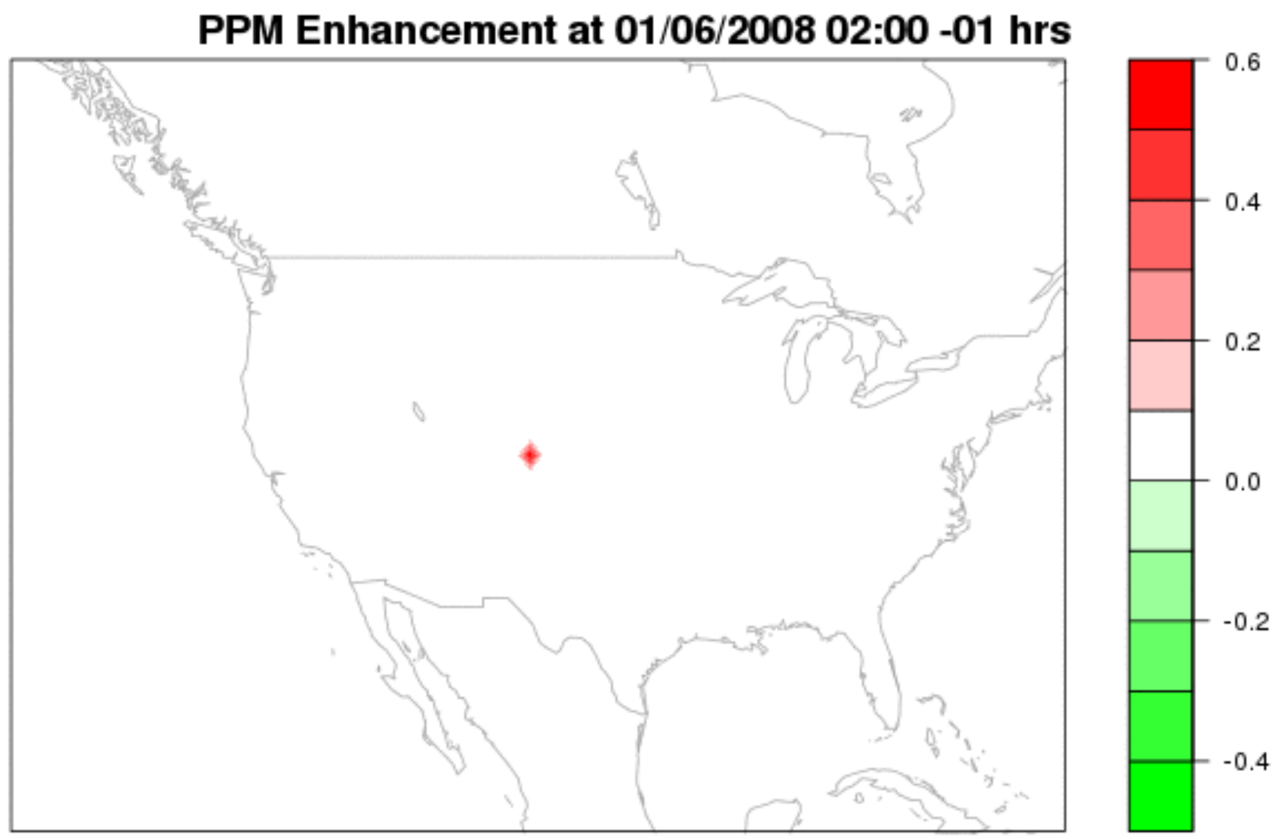


From B. Brooks

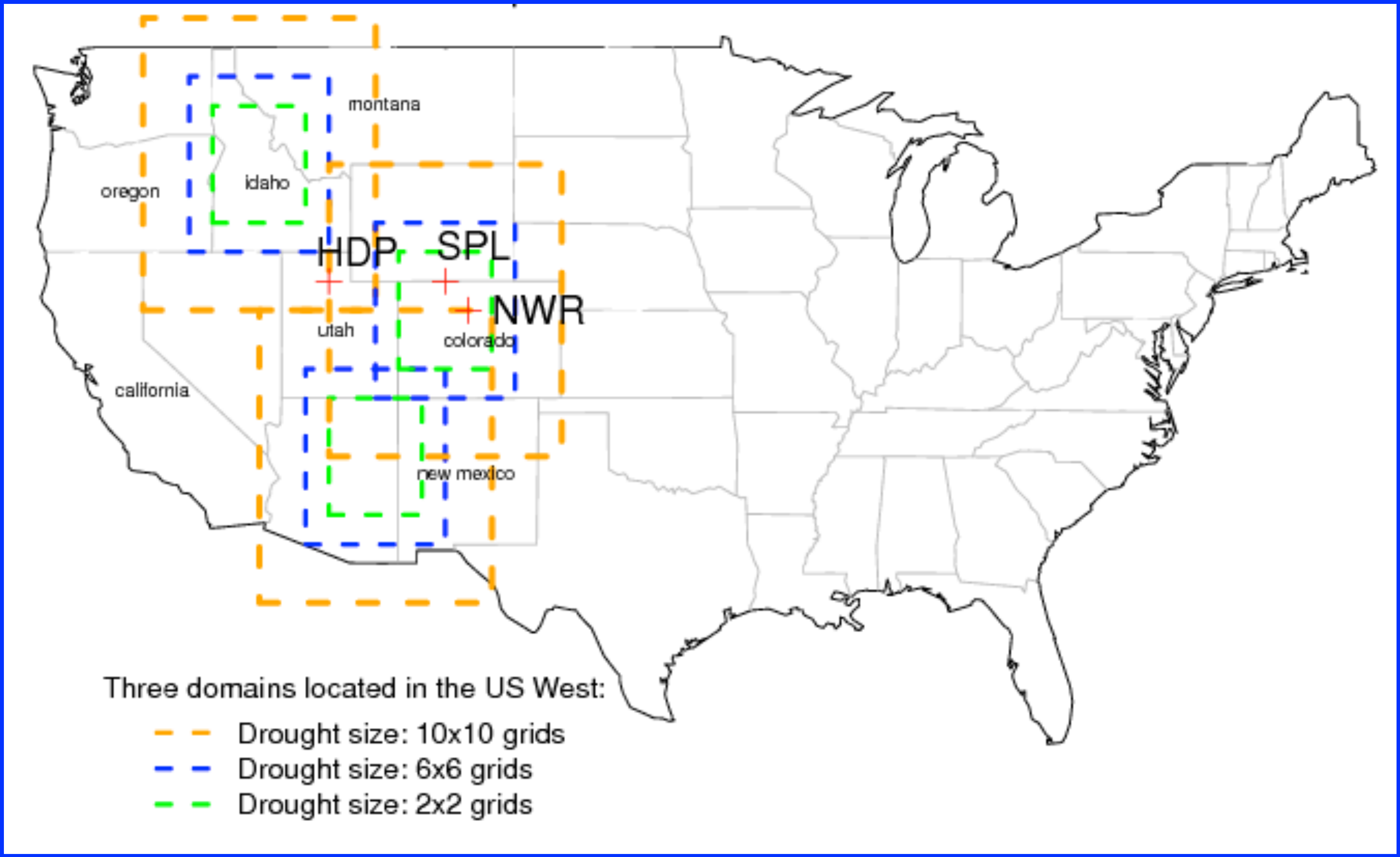
What are we looking at?



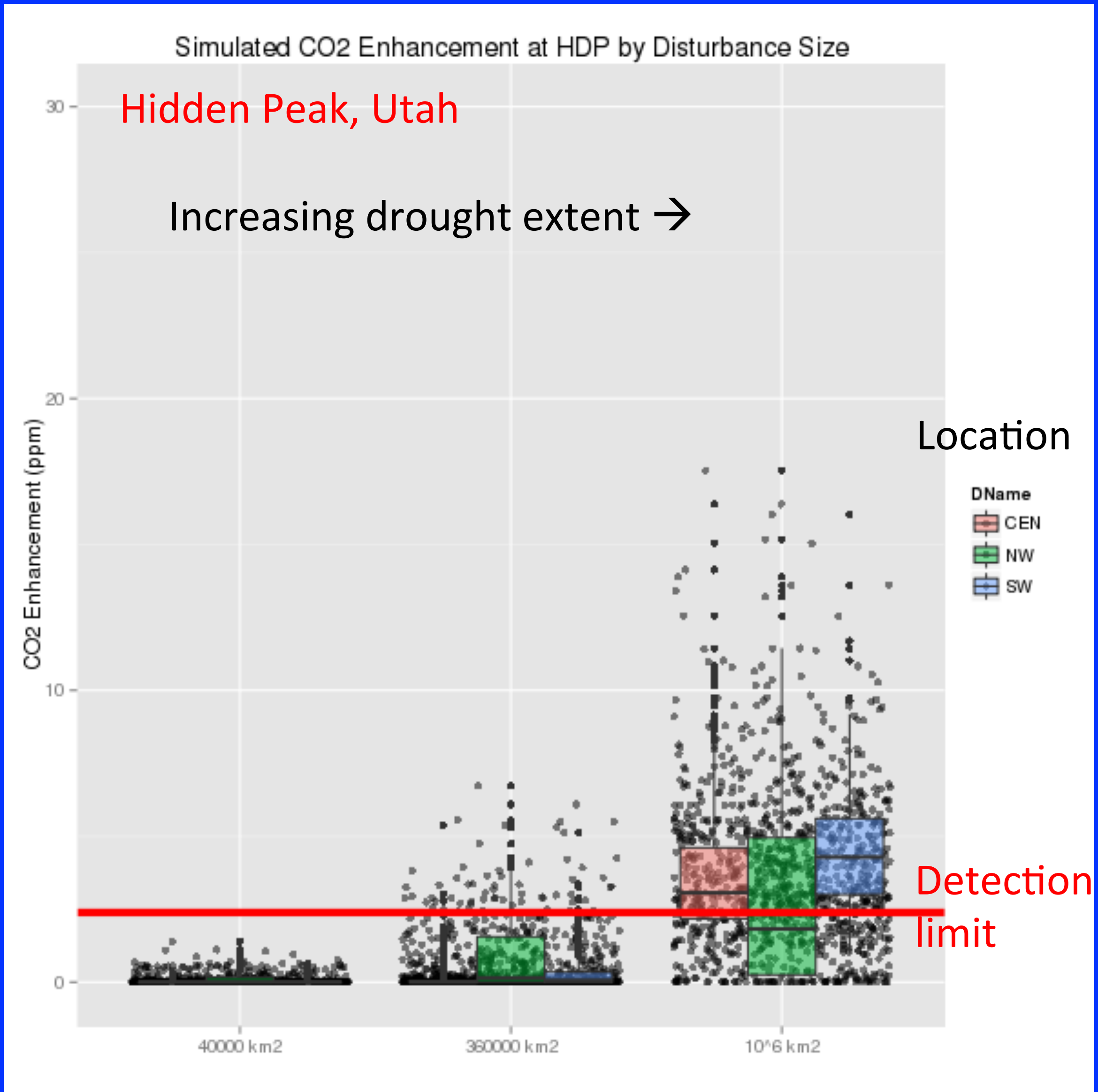
What are we looking at?



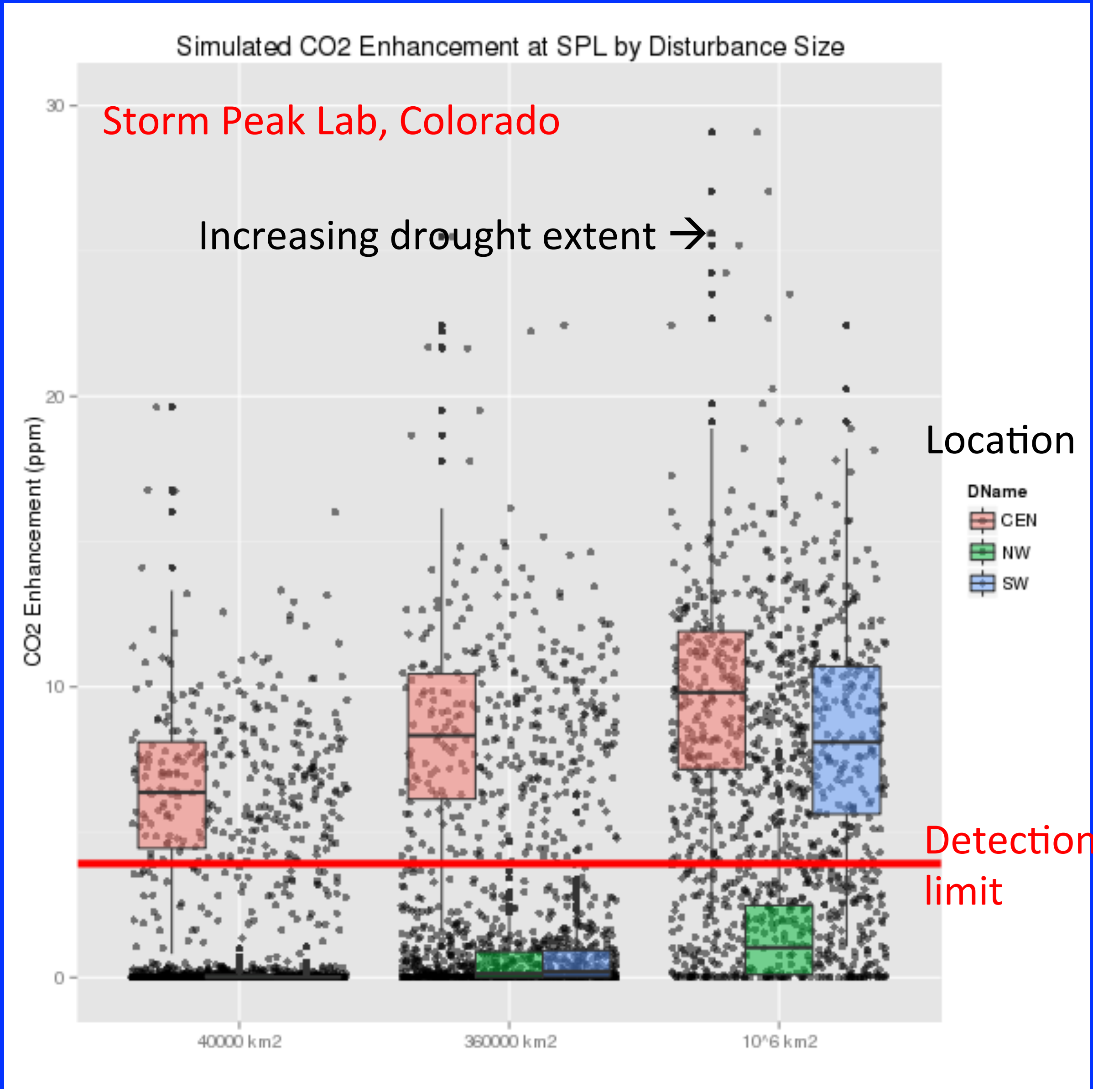
Drought simulation experiment



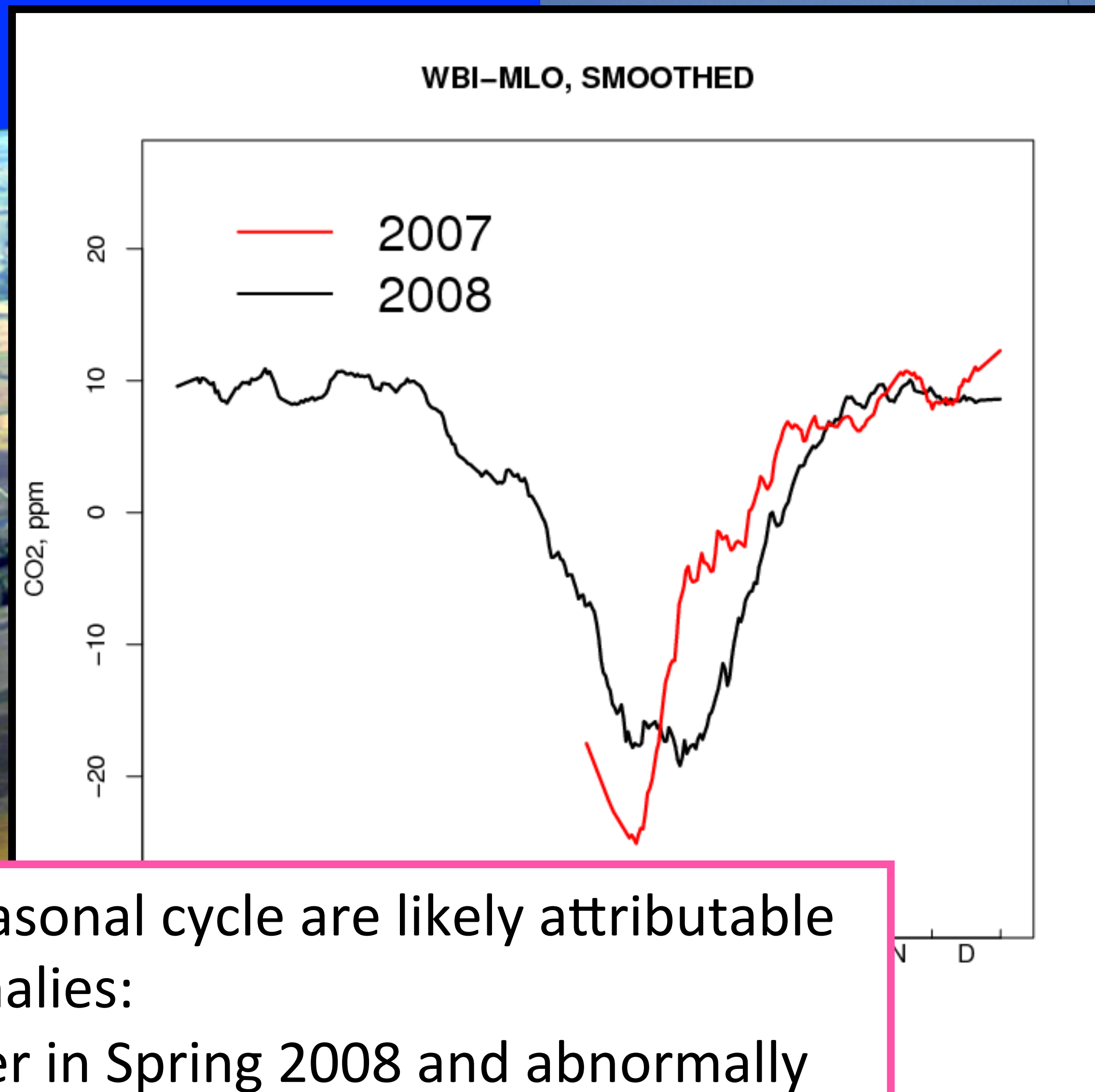
Persistent drought related emission enhances atmospheric CO2, but size and location effects detectability



As does sensor position (OSSEs are essential)



Flooding in Iowa: June 2008

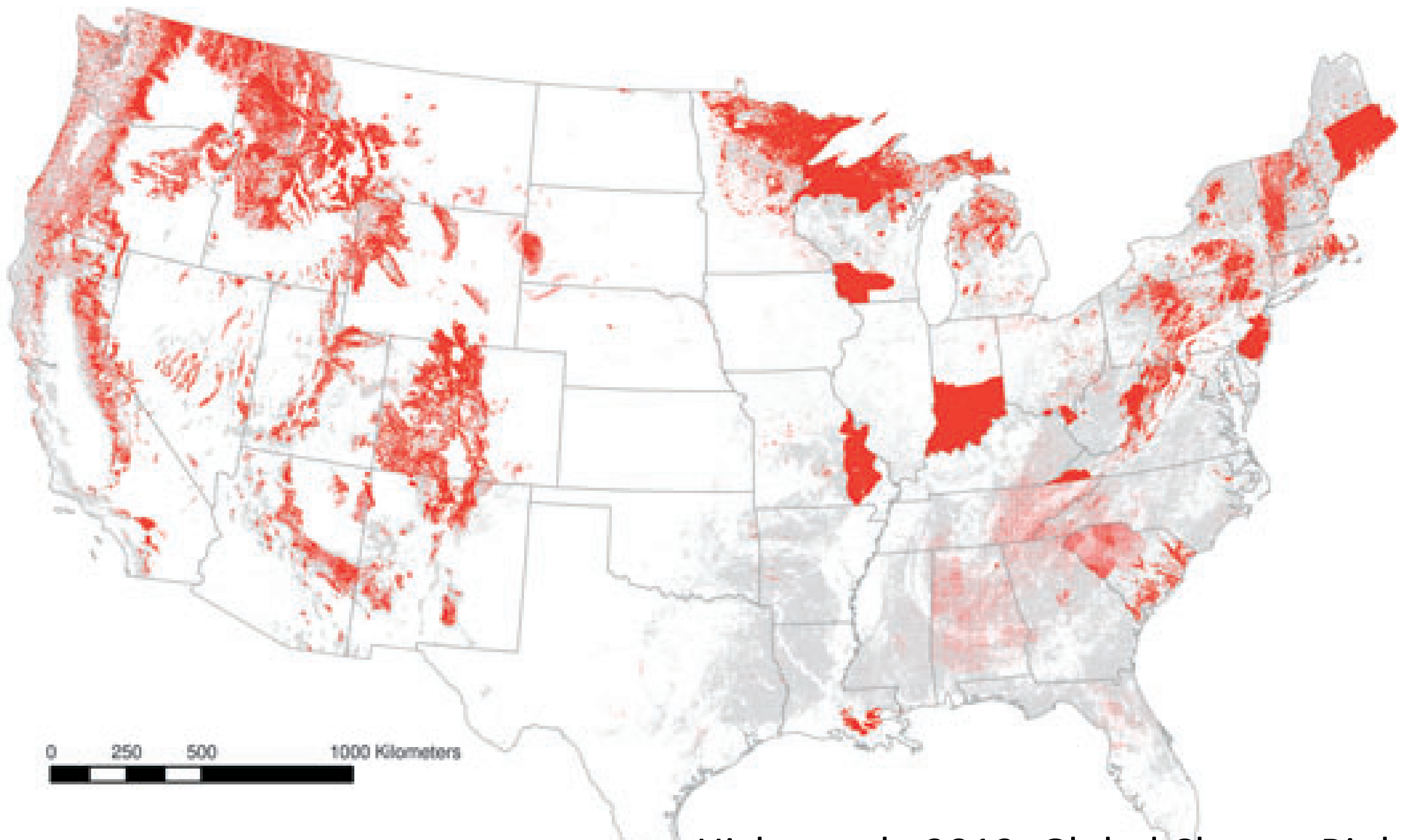


r site in
Iowa

Differences in seasonal cycle are likely attributable to weather anomalies:
Cold, wet weather in Spring 2008 and abnormally warm weather in Spring 2007.

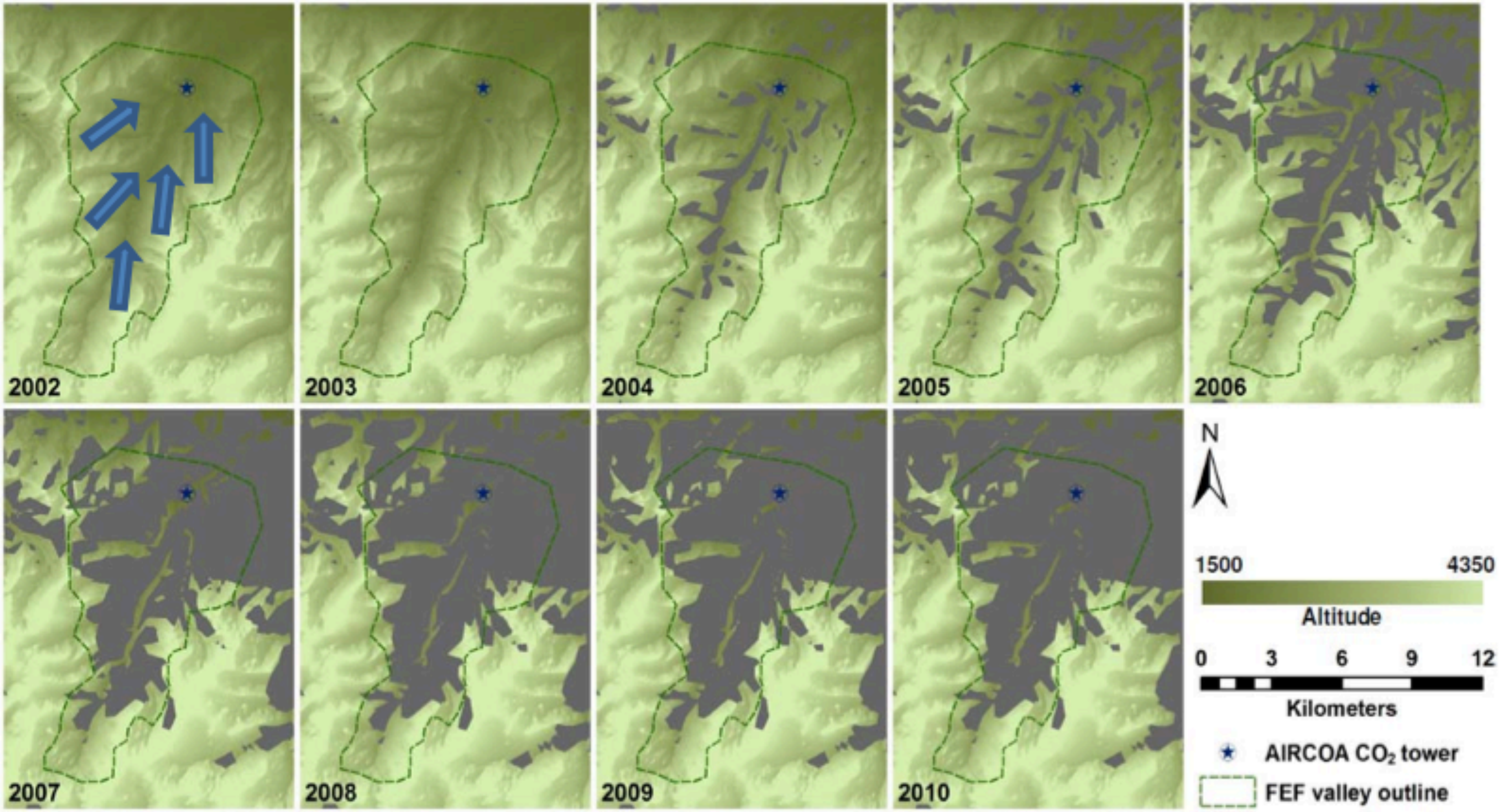
Example 2. Insects!

Moore, D.J.P., et al., 2013. Persistent reduced ecosystem respiration after insect disturbance in high elevation forests. *Ecol. Letters*, 16, 731–737, doi:10.1111/ele.12097.

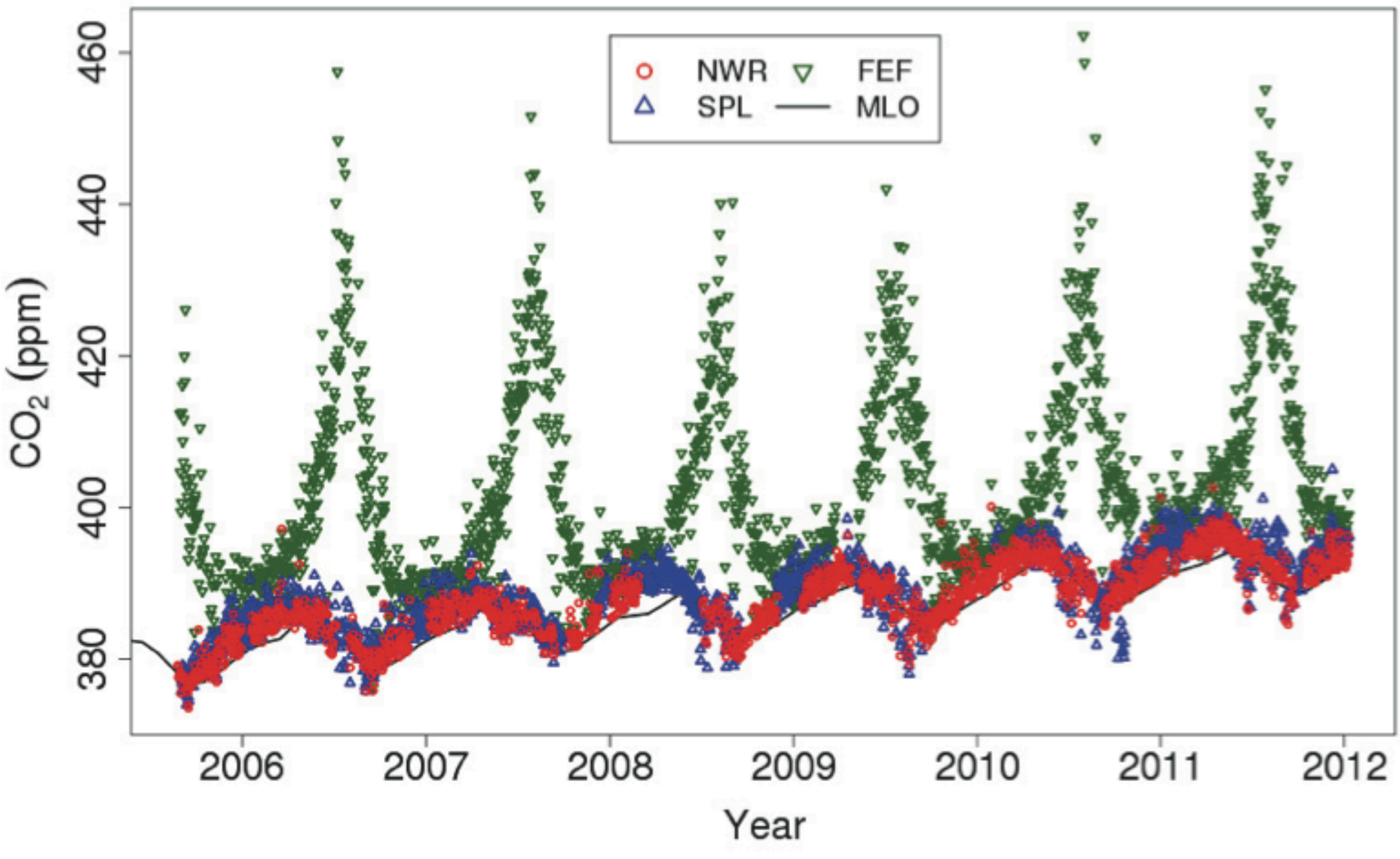


Hicke et al., 2012, Global Change Biol.

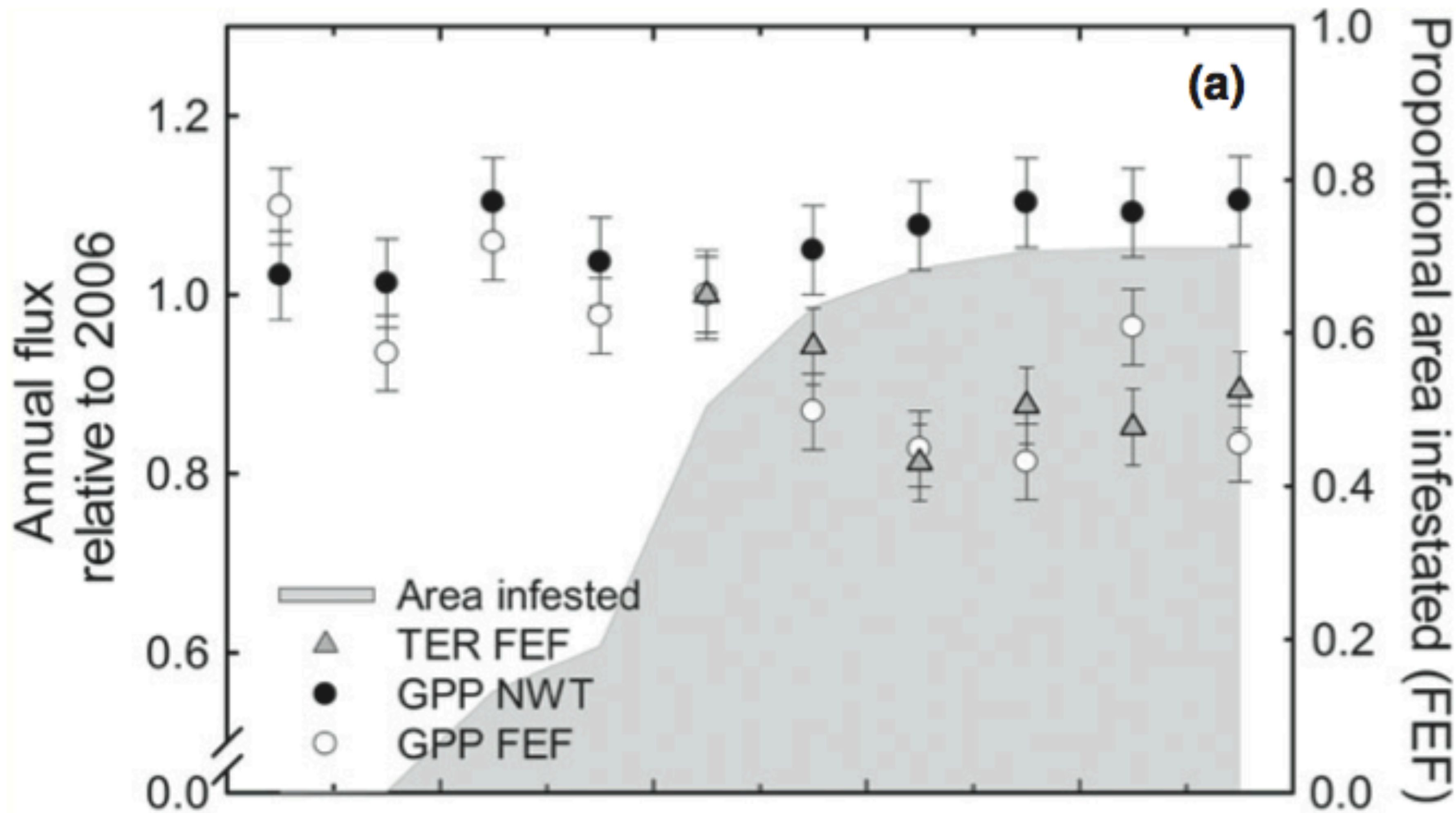
A single valley of death



And its consequences to the atmosphere

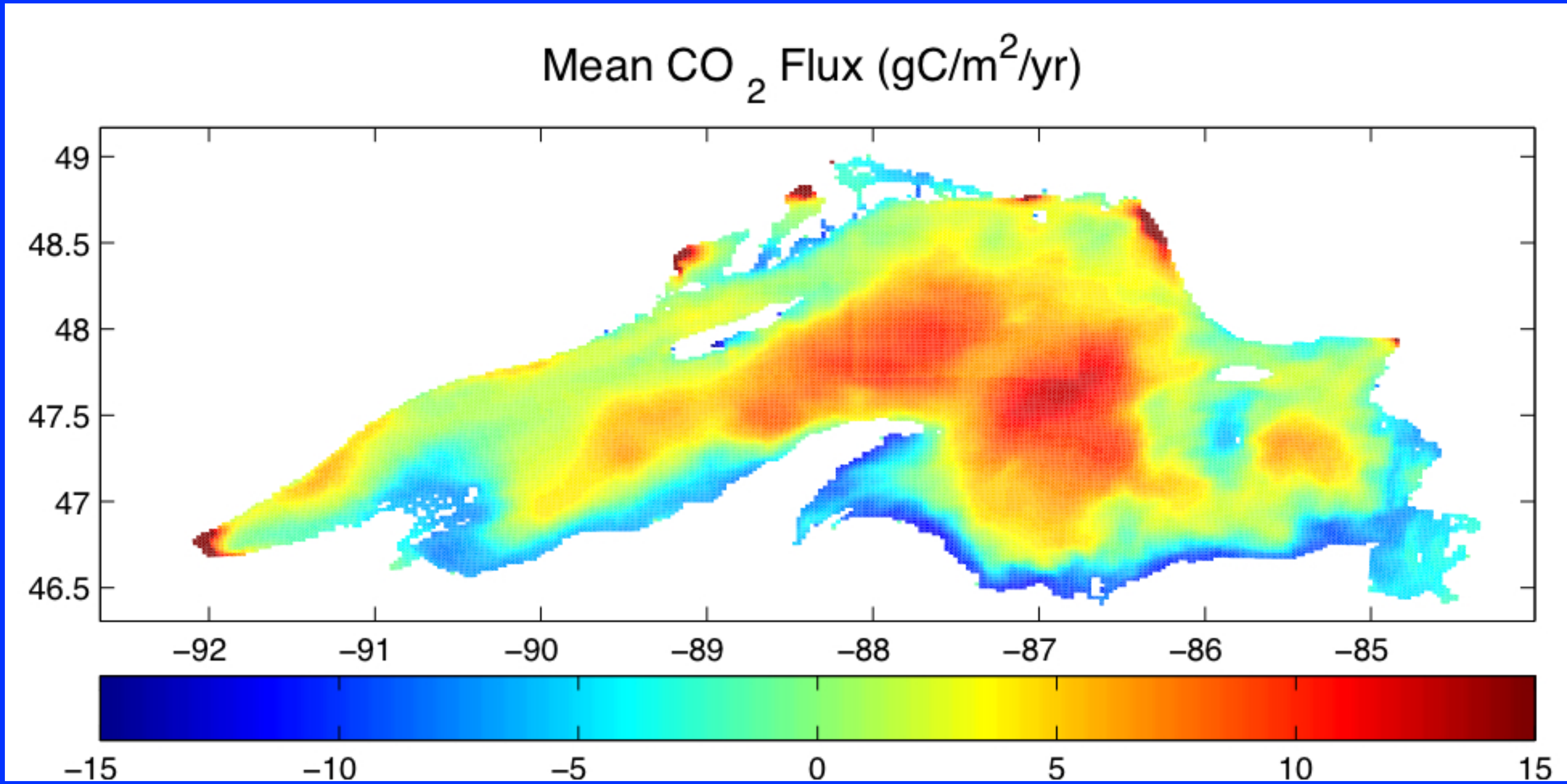


Relative changes to respiration and photosynthesis derived from concentration measurements + models

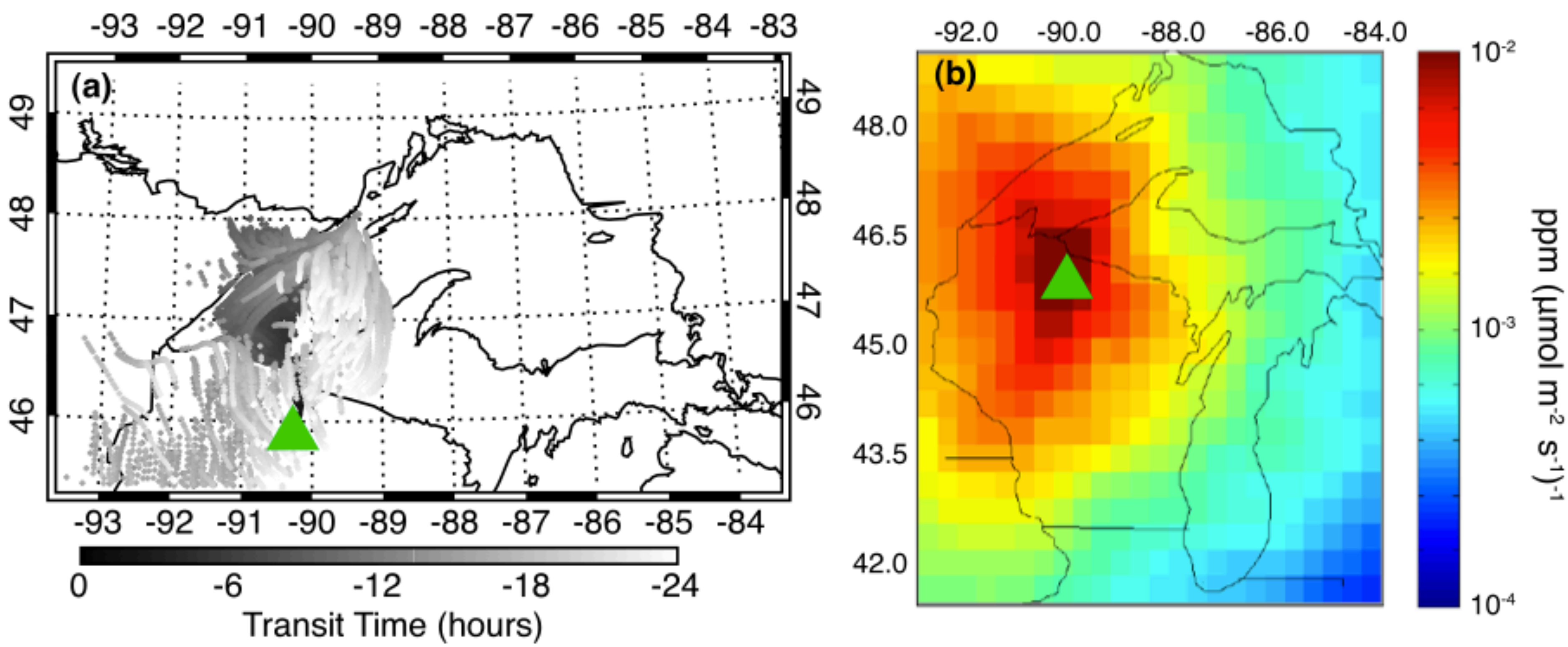


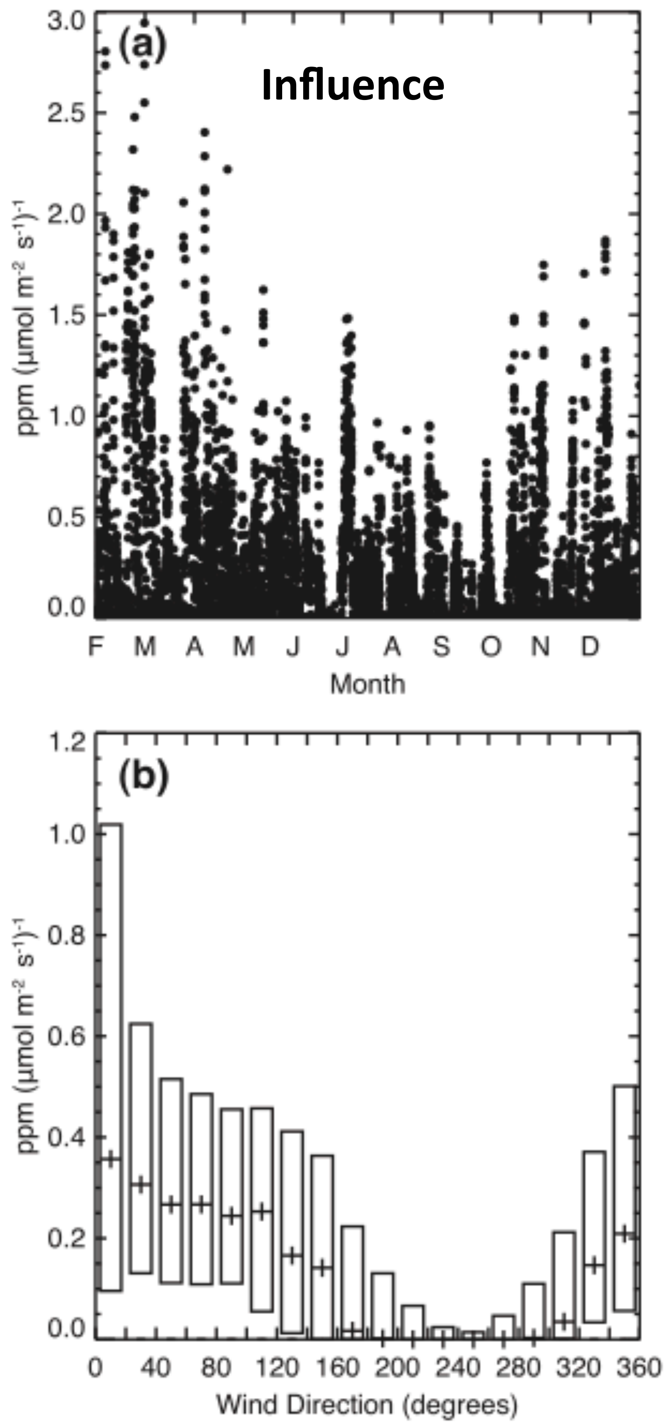
Example 3. Inland waters as hotspots?

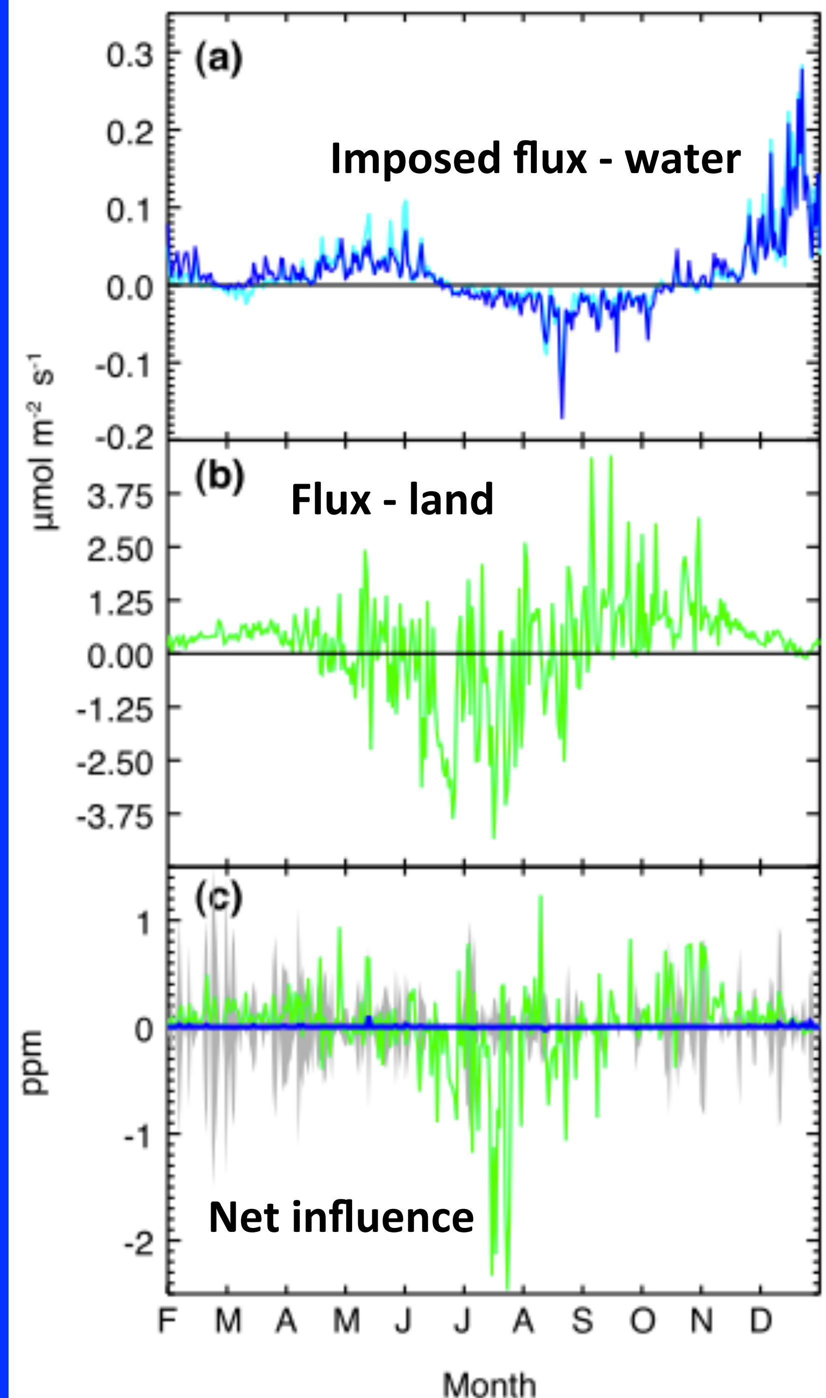
Vasys, V.N., et al., 2011. Influence of large lake carbon exchange on regional tracer transport inversions. *Environmental Research Letters*, 6 034016 doi:10.1088/1748-9326/6/3/034016.



Tower “sees” the lake

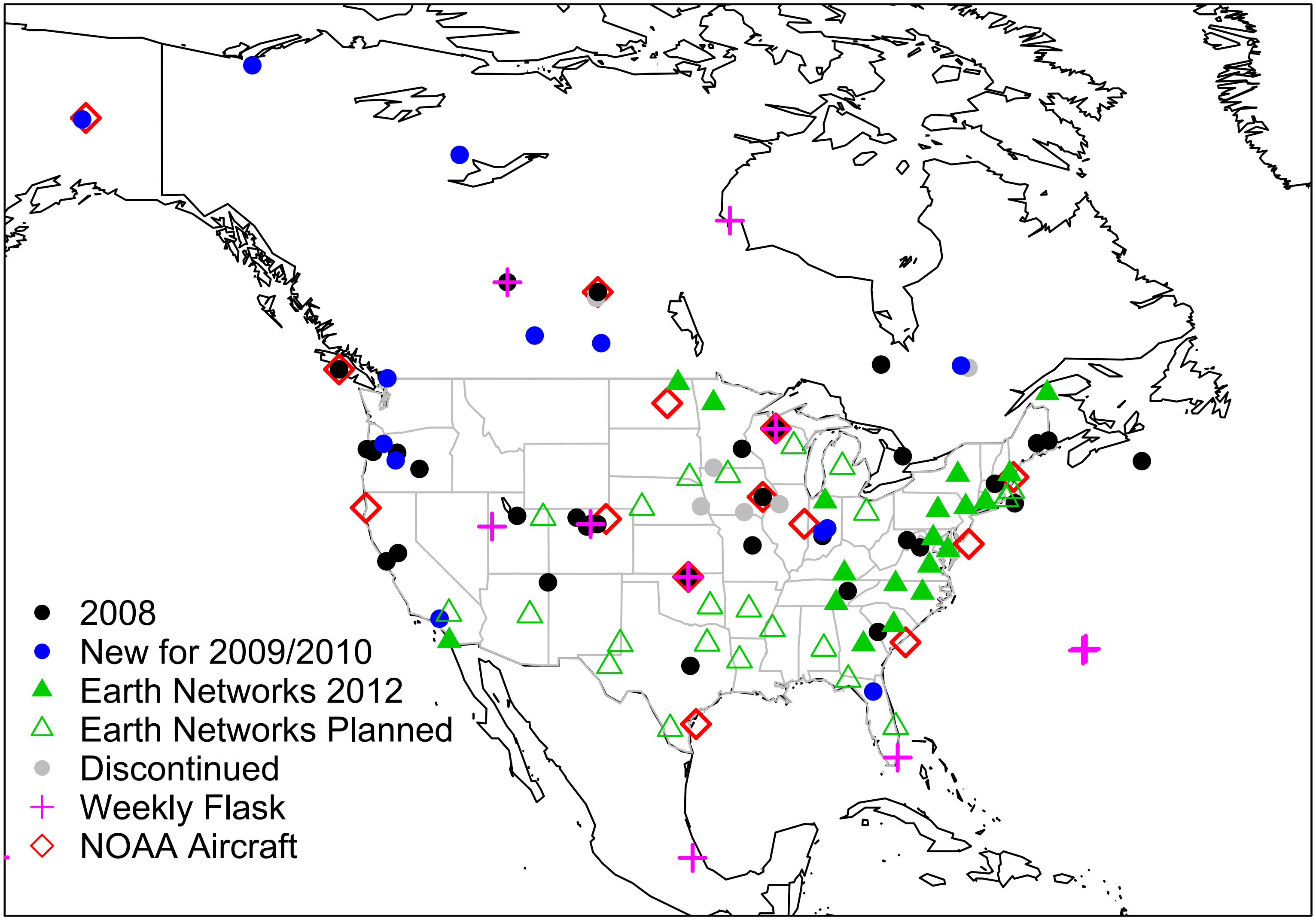



(a)
Influence
ppm (µmol m-2 s-1)-1
F M A M J J A S O N D
Month
(b)
ppm (µmol m-2 s-1)-1
Wind Direction (degrees)


(a)
Imposed flux - water
µmol m-2 s-1
(b)
Flux - land
(c)
ppm
Net influence
F M A M J J A S O N D
Month

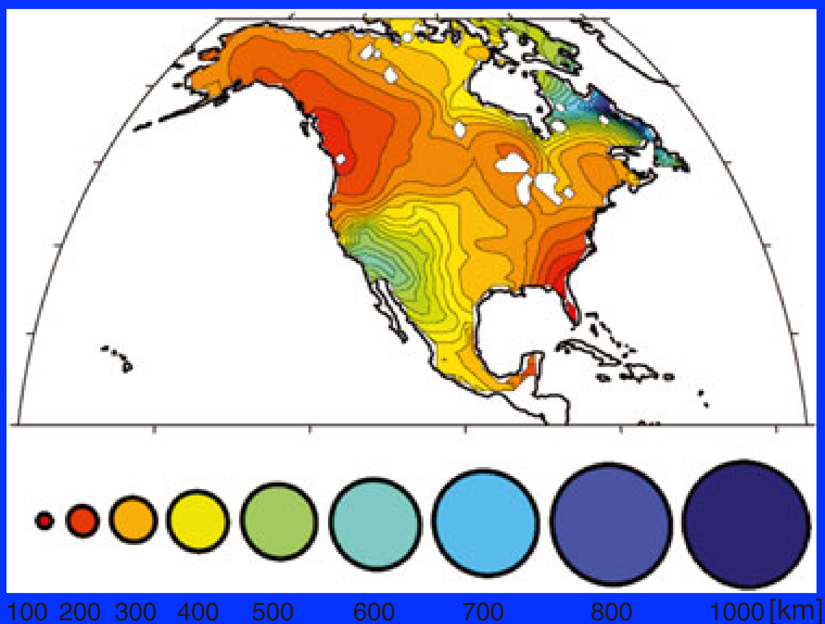
Summary and recommendations

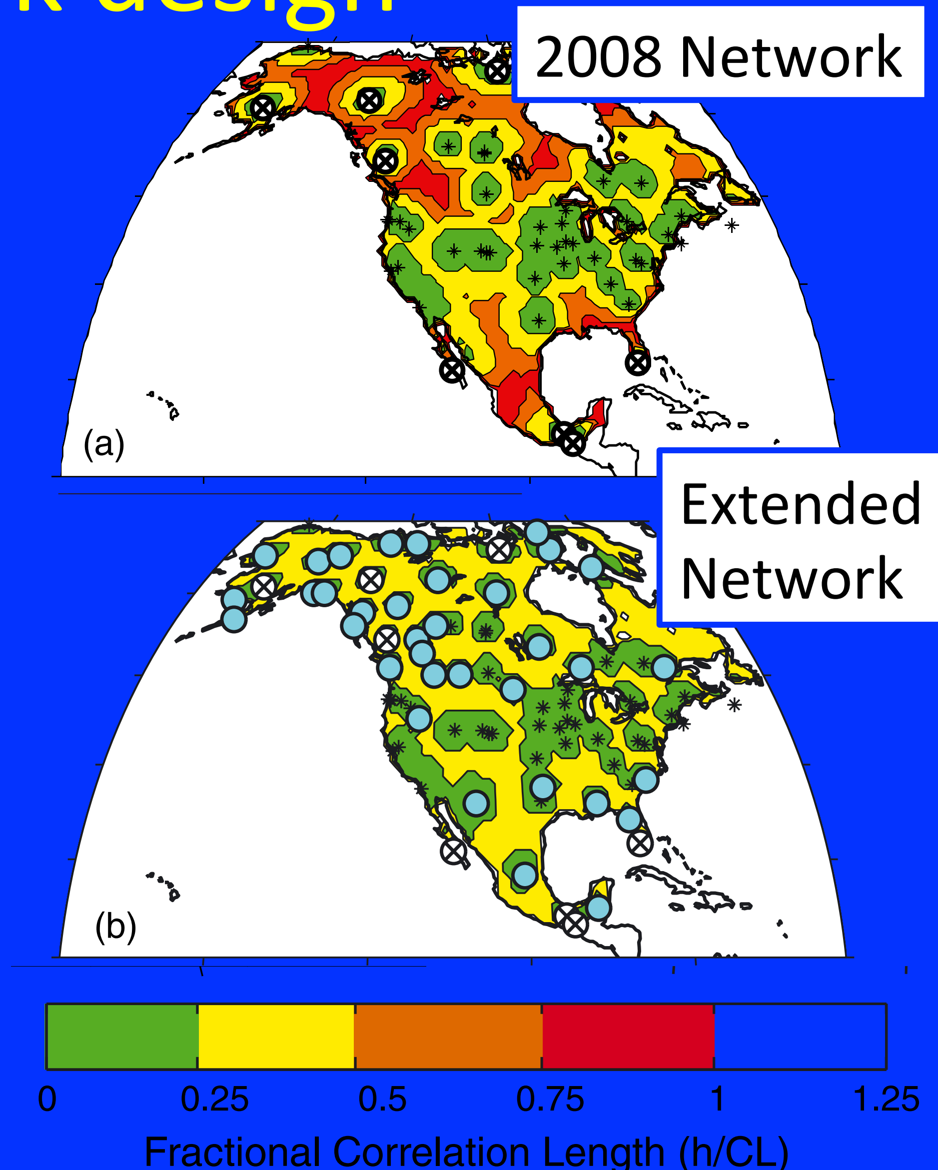
- Calibration is essential for continuous monitoring as is profiling. 0.1 ppm accuracy of CO_2 at 5 minute intervals with near zero drift is now feasible and about the level needed for regional flux quantification
- Detection of effect of extreme events on fluxes may be easier than capturing only mean fluxes
- Not every location needs to sample only well-mixed continental air masses
- Hotspot detection can lead to surprising results and provide clarity for setting inversion priors
- Transport may be the limiting factor more than observation!


2008
New for 2009/2010
Earth Networks 2012
Earth Networks Planned
Discontinued
Weekly Flask
NOAA Aircraft

Network design

Designing a network to capture the expected variability:





Y. P. Shiga, A. M. Michalak, S. R. Kawa, R. J. Engelen, "In-situ CO_2 monitoring network evaluation and design: A criterion based on atmospheric CO_2 variability", JGR, 2012

Thank you

- Collaborators: J. Kofler (NOAA), J. Thom (UW), A. Michalak (Carnegie Inst), K. Davis (Penn State), D. Moore (U Arizona), D. Huntzinger (NAU), A. Watt (NCAR), V. Vasys, tower monkeys, spectroscopy wizards, inversion gurus
- Funding: NOAA (CPO NA09OAR4310065 and NA080AR4310533), NSF (DEB-0845166), DOE (TES #ER65077)

Atmos. Chem. Phys., 12, 2099–2115, 2012
www.atmos-chem-phys.net/12/2099/2012/
doi:10.5194/acp-12-2099-2012
© Author(s) 2012. CC Attribution 3.0 License.

Atmospheric Chemistry and Physics

Assessing filtering of mountaintop CO_2 mole fractions for application to inverse models of biosphere-atmosphere carbon exchange

B.-G. J. Brooks[1], A. R. Desai[1], B. B. Stephens[2], D. R. Bowling[3], S. P. Burns[2], A. S. Watt[2], S. L. Heck[2,4], and C. Sweeney[5]

IOP Publishing — Environmental Research Letters
Environ. Res. Lett. **6** (2011) 034016 (5pp) doi:10.1088/1748-9326/6/3/034016

The influence of carbon exchange of a large lake on regional tracer-transport inversions: results from Lake Superior

Victoria N Vasys[1], Ankur R Desai[1,4], Galen A McKinley[1], Val Bennington[1], Anna M Michalak[2] and Arlyn E Andrews[3]

ECOLOGY LETTERS
Ecology Letters, (2013) 16: 731–737 doi: 10.1111/ele.12097

LETTER

Persistent reduced ecosystem respiration after insect disturbance in high elevation forests

David J. P. Moore,[1,†*] Nicole A. Trahan,[2,†] Phil Wilkes,[3] Tristan Quaife,[4] Britton B. Stephens,[5] Kelly Elder,[6] Ankur R. Desai,[7] Jose Negron[6] and Russell K. Monson[1,8]

Simulating the Impacts of Drought Disturbance on Carbon Dioxide Measurements on the US West Mountaintop by Back Trajectory Modeling

B Brooks, A. Desai, D. Hua (in prep, 2013)

CO_2, CO and CH_4 measurements from the NOAA Earth System Research Laboratory's Tall Tower Greenhouse Gas Observing Network: instrumentation, uncertainty analysis and recommendations for future high-accuracy greenhouse gas monitoring efforts

A. E. Andrews[1], J. D. Kofler[1,2], M. E. Trudeau[1,3], J. C. Williams[1,4], D. H. Neff[1,2], K. A. Masarie[1], D. Y. Chao[1,2], D. R. Kitzis[1,2], P. C. Novelli[1], C. L. Zhao[1,2], E. J. Dlugokencky[1], P. M. Lang[1], M. J. Crotwell[1,2], M. L. Fischer[5], M. J. Parker[6,7], J. T. Lee[8], D. D. Baumann[9], A. R. Desai[10], C. O. Stanier[11], S. F. J. de Wekker[12], D. E. Wolfe[1], J. W. Munger[13], and P. P. Tans[1]

Policy relevant recommendations

- Don't eat your seed corn!
  - Baseline atmospheric greenhouse gas observatories are under significant funding pressure and require a long-term plan for operation and calibration. Degradation in coverage, accuracy, and lack of group cooperation on inter-calibration and data sharing are real concerns
  - These observations are our only direct link to verifying changes to atmosphere's greenhouse gas budget
  - Don't neglect continuous tower based observations, which can now be made with high accuracy and provide a very rich picture of response of regional carbon cycle to climate change